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DEVELOPMENT, MANUFACTURING, AND TEST OF GRAPHITE-EPOXY COMPOSITE SPOILERS FOR FLIGHT SERVICE ON 737 TRANSPORT AIRCRAFT

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16. Abstract

This manufacturing and test report was prepared in compliance with the requirements of contract NAS1-11668. It documents the events and techniques employed to fabricate, verify, and certify a total of 114 graphite-epoxy flight spoilers for the 737 aircraft. Additional information is presented concerning manufacturing costs of both the graphite-epoxy components and the completed spoiler assemblies. Static test data used to substantiate the FAA certification request is also presented.

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SUMMARY

This report has been prepared to compile the events and techniques employed to fabricate, substantiate, and certify the graphite-epoxy flight spoiler for the 737 aircraft under NASA contract NAS1-11668. Since the graphite-polysulfone flight spoiler design (being developed under the same contract) is still under development, a separate report will be prepared to document its fabrication and substantiation data.

A total of 114 spoiler units were fabricated in a production-shop environment, utilizing three graphite-epoxy material systems. Production planning paper was generated for each spoiler unit to completely document each production step of each spoiler unit. The graphite-epoxy skins were laid up on production tooling using both mechanical and hand layup techniques. Inspection techniques utilized MRB-type assessment in the absence of formally documented quality requirements.

Each completed spoiler was subjected to ultrasonic inspection utilizing a multicolor recording system that documented each inspection result. In addition, one static test spoiler was sectioned after test to examine the adhesive filleting to the honeycomb core. Visual examination of the cured adhesives showed excellent results.

Three spoilers, one representing each graphite-epoxy material system employed, were static tested to destruction. Ultimate loads attained ranged from 241% to 289% of design limit load. The production 737 aluminum spoiler achieved 210% design limit load. Type certification for each of these spoiler types was obtained from the FAA predicated on the successful static test program.

INTRODUCTION

The fabrication of structural graphite-epoxy components for commercial aircraft has been largely limited to experimental-shop activities where a handful of units have been fabricated on prototype-quality tooling. While this procedure may well bear out the design concept under consideration, it does not further the confidence of engineering managers who must face the realities of large-volume production accomplished in a production-shop environment. Up to this writing, no satisfactory method short of committing a given structural design to a production run on "hard" tooling has been advanced to demonstrate this confidence. A major objective of the graphite-epoxy flight spoiler program has been to demonstrate this producibility.

The engineering design for the 737 composite flight spoiler had already been accomplished as an internal development project. Five specimens had been fabricated and tested, with changes in the prepreg material and the laminate layups being the major variables. Graphite-epoxy skin assemblies were laid up and autoclave cured. The aluminum substructure of the production spoiler design (except for the end rib) was retained. The end rib was laid up as a one-piece, five-ply fiberglass unit.

All fabrication activities, including quality control testing, were conducted at the Auburn Fabrication Division of the Boeing Commercial Airplane Company. All structural testing was accomplished in the Structural Test Laboratory of the Boeing Commercial Airplane Company. After fabrication, inspection, and certification, 108 of the spoiler units were shipped to six commercial airlines for installation and extended flight service evaluation. Documentation of the flight service portion of this program is being done annually (see refs. 1 and 2).

The following individuals have made major contributions to the material contained in this report:

Mr. Vere Thompson	Manufacturing Research and Development
Mr. Walter Keilt	Structural Test Laboratory
Mr. Robert Cook	Quality Assurance Research and Development

MANUFACTURING PROCEDURE

ADHESIVE SELECTION

A principal objective of the graphite-epoxy flight spoiler program was to demonstrate, under commercial service conditions, the ability of graphite composites to resist corrosion. Since the program offered an excellent opportunity to evaluate corrosion resistance, the latest technological materials and processes available were employed. The two areas that most profitably could be exploited were the metallic primer system and the adhesive system.

At the time the decision for selection of a primer system was to be made, Boeing was internally evaluating a new corrosion-inhibiting primer process, employing a phosphoric acid anodize. To implement this process prior to formal preparation of the process specification, the process was adapted to the special application of the spoiler program through issuance of a Boeing document (ref. 3). This process has subsequently become known as BAC 5555.

Selection of an adhesive system followed a similar philosophy. The use of a 394 K (250° F) curing adhesive was imperative, since at least one of the graphite composite systems to be utilized would cure at 394 K. The only adhesive system available at this time that met these requirements and appeared to offer satisfactory properties after exposure to 333 K (140° F) and 100% relative humidity was Hysol's EA 9628. Since this adhesive system satisfied the preliminary requirements being set down for the proposed Boeing Material Specification XBMS 5-101, EA 9628 was recommended as the adhesive for the graphite-epoxy spoilers. Adhesive property requirements are also included in reference 3. Subsequent release of Material Specification BMS 5-101 has included EA 9628 as a qualified adhesive.

The material properties specified for EA 9628 are shown in table 1, together with the range of test values obtained in qualification testing.

PROCUREMENT

GRAPHITE MATERIAL

In accordance with contract NAS1-11668, a materials screening program was conducted to select three graphite-epoxy systems from several epoxy matrixes and graphite reinforcements that were commercially available. The screening program was as follows.

- Contact graphite-epoxy vendors, establish quantity of test prepreg required, and establish delivery dates.
- Receive prepreg and fabricate test laminates.
- Prepare test specimens and condition specimens as required.

Table 1.—EA 9628 Material Properties

	Specification requirement (D6-32541)	Maximum test value	Minimum test value
	5-mil adhesive		
Lap shear, psi	4840 avg 4560 min	6460	4412[a]
Metal/metal peel, in-lb/in. width	56 avg 46 min	70.0	54.2
Honeycomb peel, in-lb/3-in. width	—	—	—
	10-mil adhesive		
Lap shear, psi	4980 avg 4860 min	6420	4560[a]
Metal/metal peel, in-lb/in. width	77 avg 67 min	78.6	64.8[a]
Honeycomb peel, in-lb/3-in. width	60 avg 47 min	73.6	57.6

[a]Qualified under MRB approval

- Coordinate with Manufacturing to evaluate prepreg for tape-laying machine adaptability.
- Conduct tests for mechanical properties and laminate and prepreg physical properties.

As a result of the screening program, Union Carbide Thornel 300/2544, Narmco Thornel 300/5209, and Hercules AS/3501 prepreg tapes were selected to fabricate the production spoilers. The graphite tape was supplied to Boeing on special reels that are a part of the Manufacturing Research and Development tape-laying equipment. Each reel is capable of holding up to 4.5 kg (10 lb) of 76-mm (3-in.) tape material.

The graphite tape material was procured to meet a set of requirements established by Engineering to ensure a level of quality consistent with aircraft-quality structure and the requirements of the tape-laying equipment used on this program. Among the requirements were:

- Control of graphite tape width to +0.000, -0.38 mm (-0.015 in.)
- Control of release paper width to +0.000, -0.38 mm (-0.015 in.)
- Control of release paper quality by weight to 36 kg per 278 m^2 (80 lb per 3000 ft^2)
- Limitation of frequency of tape splices to no more than one every 46 m (150 ft)
- Control of gaps between rows 0.76 mm (0.03 in.) wide by 51 mm (2.0 in) long and frequency of gaps to not more than 2 per cross section or 12 per running meter of tape

- Limitation of frequency of defects such as crossovers and folds to not more than 1 in 30 m of tape, with such defects to be plainly marked to facilitate removal

- Control of cured ply thickness to 0.14 mm (0.0055 in.) ±0.013 mm (0.0005 in.)

- Control of room temperature mechanical properties to the following minimums:

  $F_{tu} = 1137(10^6)$ Pa (165 000 psi)

  $F_s = 68.9(10^6)$ Pa (10 000 psi)

  $E_t = 117.2(10^9)$ Pa (17.0×10^6 psi)

- Control of fiber volume to 60% ±2%

Table 2 summarizes mechanical properties of the material systems selected from the screening program. Table 3 summarizes mechanical properties of samples made concurrently with graphite skin fabrication.

Table 2.—Mechanical Property Summary of Selected Composite Systems

Testing property	Narmco T300/5209		Union Carbide T300/2544		Hercules AS/3501	
	Boeing data	Vendor data	Boeing data	Vendor data	Boeing data	Vendor data
Compression ultimate						
0° at RT	889 (129.0)	1103 (160.0)	859 (124.6)	1186 (172.0)	865 (125.5)	
0° at RT 30 days 333 K (140° F) 0° at 344 K and 100% RH	774 (112.2)	748 (108.5)				
Compression modulus						
0° at RT	132.4 (19.2)	117.2 (17.0)	148.2 (21.5)	155.1 (22.5)	100.0 (14.5)	
Tensile ultimate						
0° at RT	1110 (161.0)	1172 (170.0)	1340 (194.3)	1200 (174.0)	1311 (190.2)	1393 (202.0)
0° at 344 K (160° F)	1221 (177.1)		1422 (206.2)		1241 (180.0)	
90° at RT	36.5 (5.3)		17.9 (2.6)		35.9 (5.2)	
90° at 344 K (160° F)	31.0 (4.5)		32.4 (4.7)		28.3 (4.1)	
Tensile modulus						
0° at RT	117.2 (17.0)	124.1 (18.0)	163.4 (23.7)	141.3 (20.5)	124.1 (18.1)	106.9 (15.5)
0° at 344 K (160° F)	131.7 (19.2)		178.6 (25.9)		135.8 (19.7)	
90° at RT	10.8 (1.56)		14.3 (2.07)		12.5 (1.82)	
90° at 344 K (160° F)	8.5 1.24)		11.9 (1.73)		12.1 (1.75)	
Short-beam shear						
0° at RT	82.0 (11.9)	96.5 (14.0)	54.5 (7.9)	103.4 (15.0)	93.1 (13.5)	93.8 (13.6)
0° at 344 K (160° F)	66.9 (9.7)		47.6 (6.9)		75.8 (11.0)	
0° at RT, 30 days 333 K (140° F) and 100% RH	68.9 (10.0)		44.1 (6.4)			
% fiber volume (laminate)	54.0	62-64	68.0	≈ 60.0	55.0	56.0
% resin solids (prepreg)		≈40.0		≈ 40.0		≈ 38.0

[a]Valves given in GN/m^2 for modulus, MN/m^2 for stress
( ) values given in msi for modulus, ksi for stress

Table 3.—Mechanical Property Sampling Data (Skin Laminates)[a]

Test property	Narmco T300/5209		Union Carbide T300/2544		Hercules AS/3501	
	Boeing data	Vendor data	Boeing data	Vendor data	Boeing data	Vendor data
Compression ultimate 0° at RT	—	1103 (160.0)	—	1186 (172.0)	—	—
Compression modulus 0° at RT	—	117.2 (17.0)	—	155.1 (22.5)	—	—
Tensile ultimate 0° at RT	1319 (191.3)	1172 (170.0)	1334 (193.7)	1200 (174.0)	1452 (210.6)	1393 (202.0)
Tensile modulus 0° at RT	136.5 (19.8)	124.1 (18.0)	155.1 (22.5)	141.3 (20.5)	119.3 (17.3)	106.9 (15.5)
Shor-beam shear 0° at RT	77.9 (11.3)	96.5 (14.0)	74.5 (10.8)	103.4 (15.0)	84.1 (12.2)	93.8 (13.6)

[a] Values given in GN/m^2 for modulus, MN/m^2 for stress
( ) Values given in msi for modulus, ksi for stress

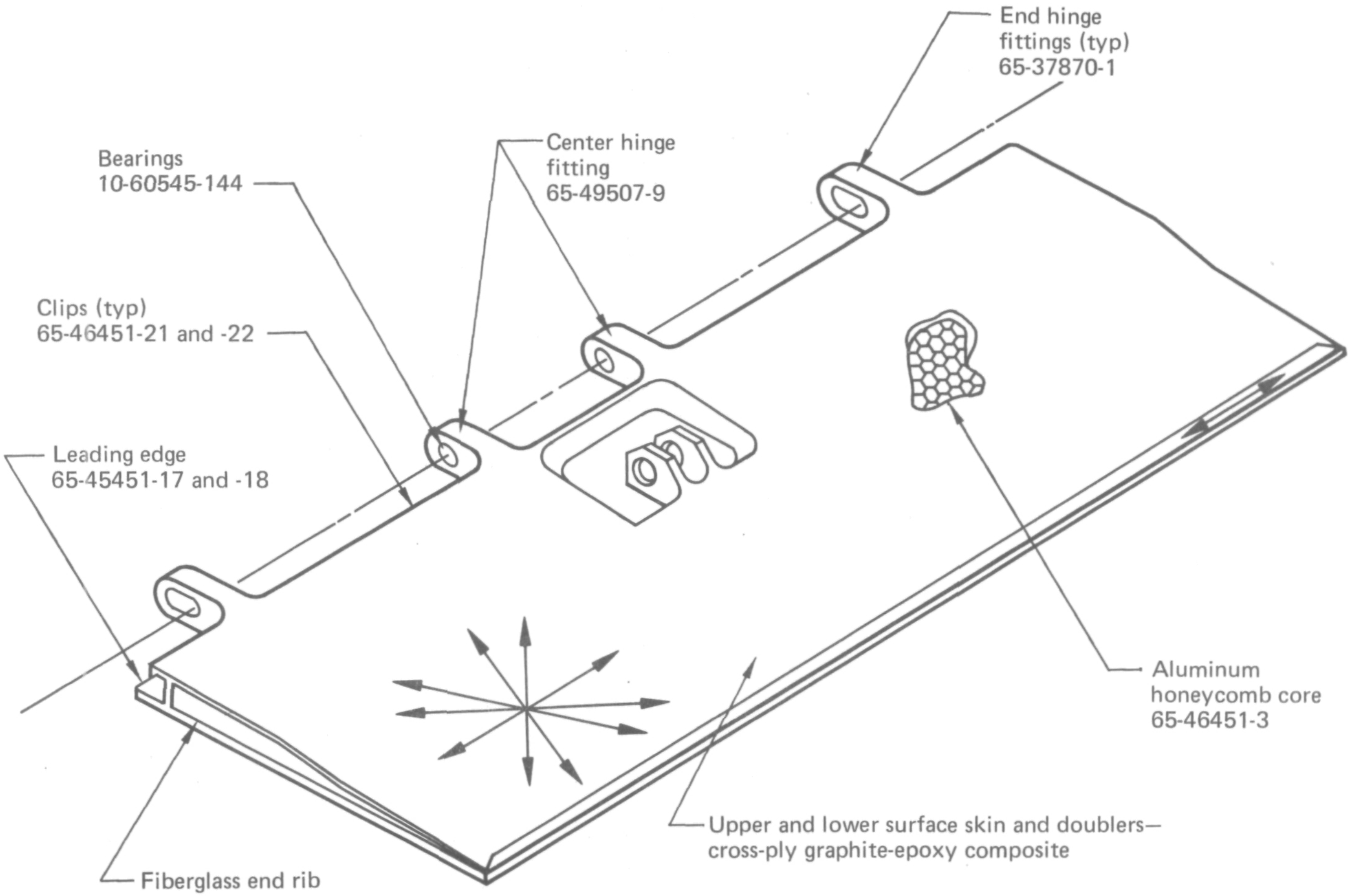
ALUMINUM DETAILS

All aluminum detail components common to the composite spoiler and the production 737 spoiler were purchased from the current spoiler subcontractor. Appropriate purchasing orders were placed with the subcontractor to supply these components on a schedule that would support the established production rate. These components are listed in table 4.

Figure 1 shows the relationships of the essential metal details. Engineering drawing 65-76327 appended to this report describes these components in detail.

Table 4.—Aluminum Detail Components

Part number	Part name	Material designation
65-49507-8	Center hinge fitting	7079-T6 aluminum forging
65-37870-1	End hinge fitting	7079-T6 aluminum forging
65-76327-21	Honeycomb core	5052 aluminum alloy, corrosion resistant, 4.78-mm (3/16-in.) cell, 0.010 gage, nonperforated
65-46451-21	Clip	7075-T6 extrusion
-22	Clip	7075-T6 extrusion
65-46451-17	Leading-edge channel	7075-T6 extrusion
-18	Leading-edge channel	7075-T6 extrusion
10-60545-144	Bearing	Teflon fabric; self-aligning



Note: All structure is adhesively bonded

Figure 1.—Details of 737 Graphite-Epoxy Flight Spoiler

TOOLING

Table 5 identifies the major tools fabricated for this program and gives the purpose for each. These tools were designed and fabricated as regular production tooling and would be representative in cost and usage of production units.

Table 5.—Major Tooling Compilation

Tool code	Tool name	Approximate tool size, mm	(in.)
XAJ	Spoiler frame assembly jig	914 x 1561	(36 x 65)
XBAJ	Flight spoiler panel assembly jig	914 x 1561	(36 x 65)
XLM	Upper surface skin layup mandrel	1778 x 2540	(70 x 100)
XLM	End rib layup mandrel	457 x 1219	(18 x 48)
XLM	Lower surface skin layup mandrel	1778 x 2540	(70 x 100)
XBAJ	Honeycomb bond assembly fixture	914 x 1561	(36 x 65)
BMF	Bond mill fixture	1067 x 1829	(42 x 72)

The following describes the functions of the spoiler tools.

- *Frame assembly jig* (XAJ 65-76318-3). This tool is used for locating and holding detail parts, for drilling full-size fastener locations from pilots in details, and for riveting detail parts into 65-76327-9004 frame assembly.

- *Flight spoiler panel assembly jig* (XBAJ 65-76318-1). The panel BAJ is provided for locating and holding the -3 frame assembly, the -5 lower and -6 upper graphite skins, and the -9 and -25 doublers during the 379 K/241(10^3) Pa (225° F/35 psi) bond cycle. The tool is also used for the two other spoiler configurations that use different graphite material for skins. Spoiler assembly support tooling includes:

    1. XJDT 65-76318-1: a template to show locations of holes common to seals, fillers, end ribs, skins, and channels.

    2. XSHF-5 and -8: shaper fixtures for locating, holding, and trimming outer periphery of the assembly to net configuration.

- *Upper surface skin layup mandrel* (XLM 65-76318-6). This steel tool is used for layup, trim, and cure of four flat graphite skins at one time. The tool is used in conjunction with the tape-layup machine. It has index pins in the excess for locating and holding net-trim templates.

- *End rib layup mandrel* (XLM-3). The rib mandrel provides for layup and cure of -3 and -4 fiberglass end ribs on one tool. A shaper fixture is used to hold and trim the ribs and to make a taper in the -5 wedge strip after bonding.

- *Lower surface skin layup mandrel* (XLM 65-76318-5). This high-temperature fiberglass tool (fig. 2) is used to lay up, trim, and cure four contoured graphite skins at one time. The tool uses the methods established in reference 4. It is used in conjunction with the tape-layup machine and, similar to the -6 tool, has index pins in the outer excess for locating and holding trim templates.

- *Honeycomb bond assembly fixture* (XBAJ 65-76318-3). This fixture (fig. 3) provides for locating and holding the 65-76327-9004 frame assembly and the 65-76327-21 honeycomb core during the bond cycle.

- *Bond mill fixture* (BMF 65-17348-3). The mill fixture is a Boeing 727 spoiler tool that has an interchange support bar with hinge point locator for the 737 graphite spoilers.

SPOILER PRODUCTION

Figure 4 shows the composite spoiler production schedule, together with the preproduction activities of tooling and procurement necessary prior to production of the first unit. Spoiler production was expected to reach a maximum rate of one per day.

The number of completed spoiler units did not match the scheduled completion curve (fig. 4). Several problems associated with the startup of production account for this difference. Among these problems were:

- Inability of bond assembly jig to maintain the -4 honeycomb assembly in position prior to second-stage bonding of graphite skins

- Inability of bond assembly jig to maintain graphite skins in proper position during bonding operation

- Mechanical malfunction of multilevel color C-scan equipment, which delayed nondestructive test (NDT) operations for a period of 4 weeks (periodic verifilm operations were utilized as an assist during this period)

- Engineering error in end rib design, which necessitated tool rework and scrappage of initial production of end ribs

While the composite spoiler production rate did not meet the originally established schedule, all the spoiler shipments to the participating airlines were met as scheduled.

In general, the procedure for production of the spoilers (fig. 5) consisted of:

- Machine laying and autoclave curing the graphite-epoxy flat and contoured skins

- Chemically cleaning and priming the aluminum spar details (hinge fitting, leading-edge channel, end ribs, and clips)

- Riveting together the spar details

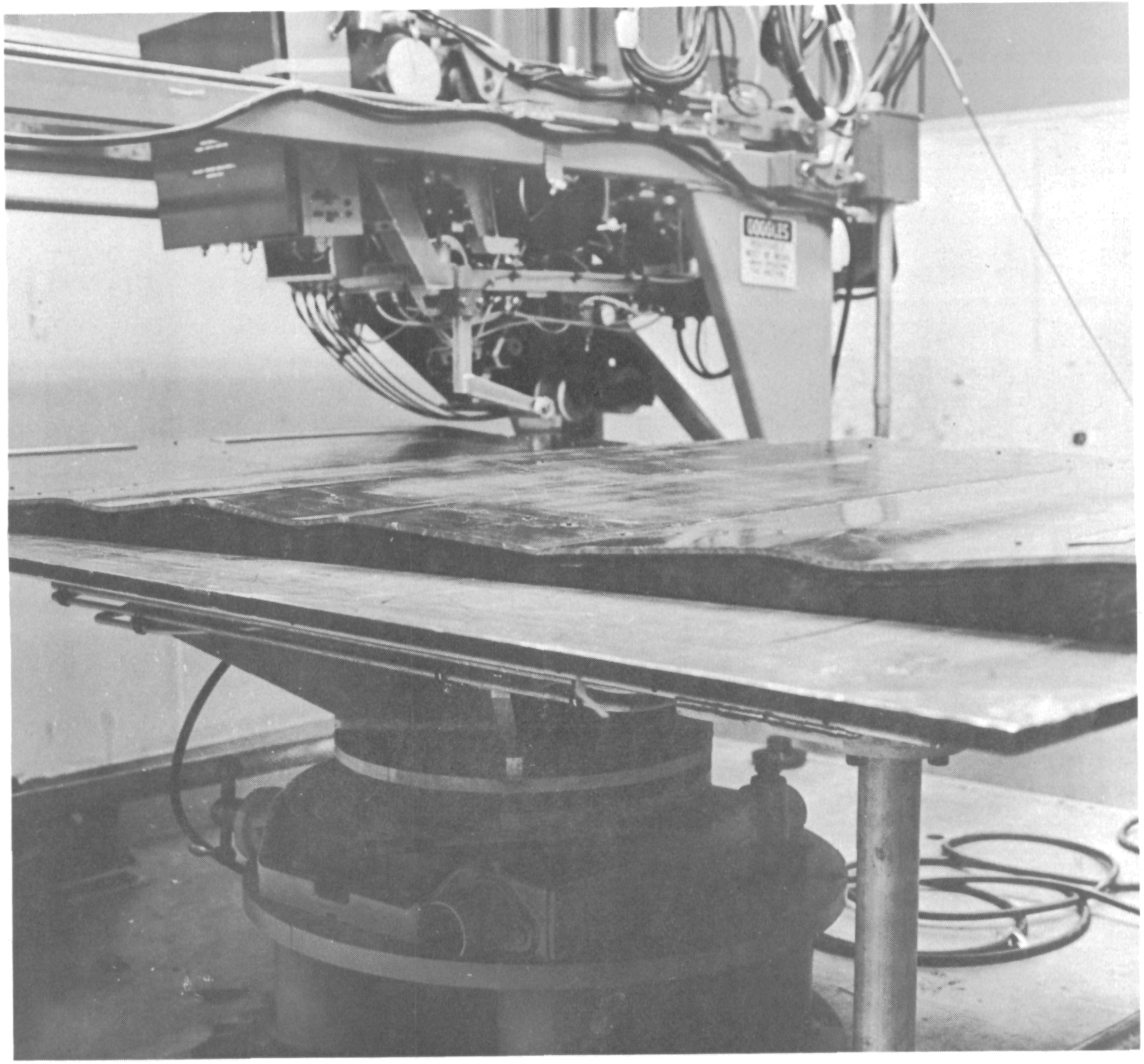


Figure 2.—High-Temperature Fiberglass Tool

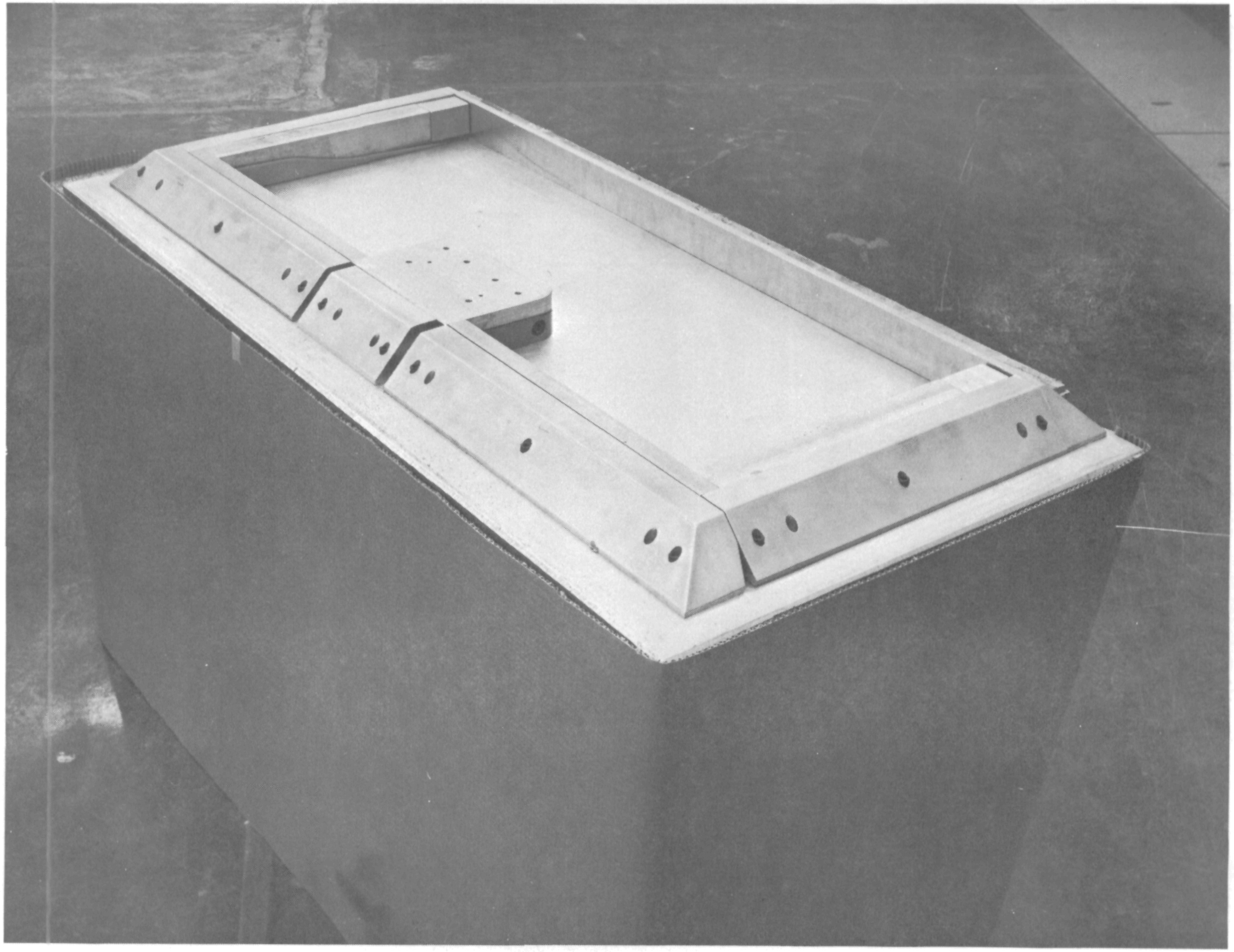


Figure 3.—Honeycomb Bond Assembly Fixture

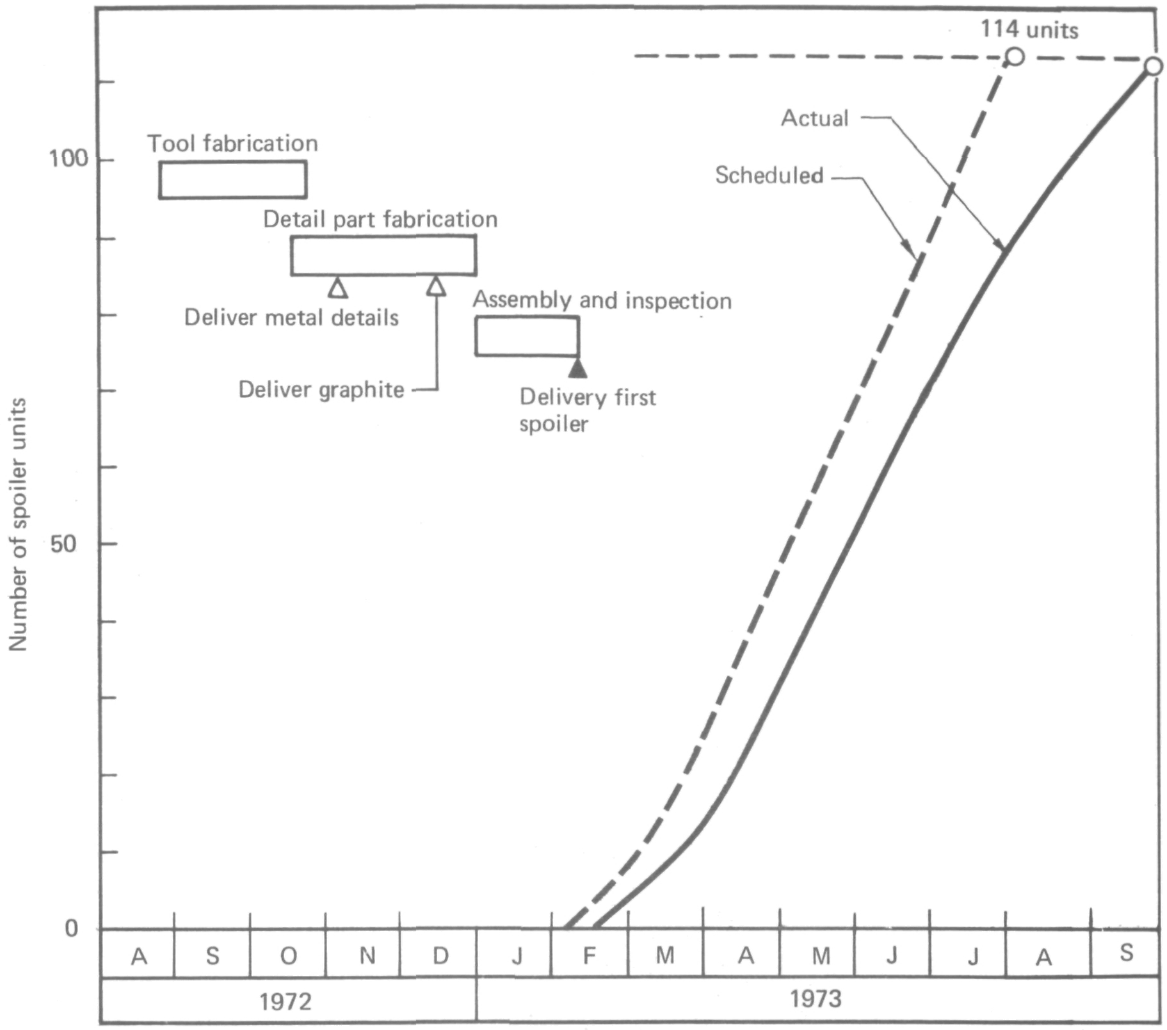


Figure 4.—Composite Spoiler Production Schedule

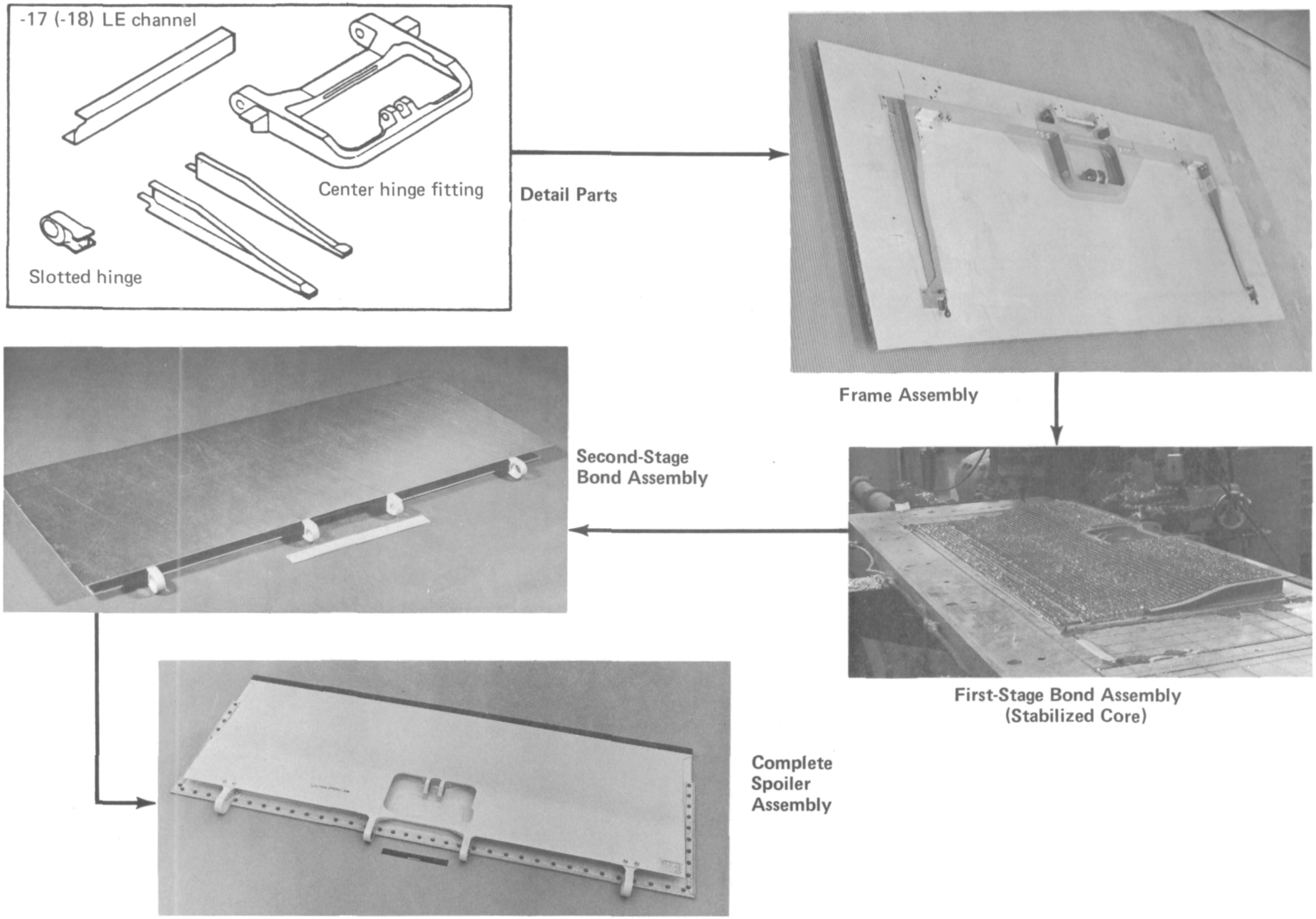


Figure 5.—Spoiler Assembly Sequence

- Bonding the spar subassembly to aluminum core; core stabilized with film adhesive, then bonded to spar

- Machining the core and assembly bonding the graphite-epoxy skins and spar-core subassembly

Since program requirements dictated that all spoilers carry unique identification via serial numbers, the system of serial number assignment shown in table 6 was utilized for identification.

Table 6.—Serialization Schedule

Graphite tape supplier	Spoiler part number	Serial numbers assigned
Union Carbide	65-76327-1	0001–0040
Narmco	65-76327-2	0041–0080
Hercules	65-76327-3	0081–0120

Another contractual requirement for this program was the establishment of an "accountability log." This log was intended to contain the production records relating to each individual spoiler unit so that future events in the environmental exposure portion of the program could be referred back to the production records for explanation and/or problem solutions. Since the production planning paper carried all the detailed production information for each individual spoiler unit, plus the paperwork relating to special handling or repairs associated with a particular spoiler, the planning paper itself was preserved by the program manager as the accountability log, together with any special paper (such as NDT records), to permit a review of each spoiler's fabrication history and/or physical status at time of delivery to the participating airline.

Preparation of the graphite-epoxy tape and adhesive-bonding operations were performed in a limited contamination area that met the requirements specified below.

- The room shall not be a thoroughfare and entry shall be restricted to those actually involved in fabrication operations.

- The temperature shall be maintained at 288 to 300 K (60° to 80° F).

- No smoking or eating shall be allowed.

- The area shall be kept closed. Doors and openings shall be closed when not in use.

- All materials, tools, parts, or equipment shall be free of dirt, oil, grease, or other contaminants.

- The use of unapproved parting agents, silicone lubricants, grease, talc, waxes, or similar materials is prohibited in the limited contamination area.

- Table tops, cutting tools, and hand tools shall be wiped with methyl ethyl ketone (MEK) at the beginning of each shift of operation.

- The floor shall be swept and vacuum cleaned at the end of each shift. The floor shall be damp mopped at least once per week.

- Overhead construction shall be cleaned at least once per month.

- No process or operation that produces dust, spray, fumes, or particulate matter shall be permitted within the limited contamination area.

- A positive pressure differential shall be maintained so that unfiltered air does not enter the area through access doors or other openings.

- All personnel within the limited contamination area shall wear clean white gloves unless a specific operation requires use of bare hands.

- Inlet filters on the air supply system shall be changed at least once per month.

GRAPHITE SKIN FABRICATION

One of the manufacturing goals of the program was to reduce the layup time for the graphite skins to 4.1 man-hours per skin. Layup time in this report includes tool preparation, laying and trimming of the graphite skins, damming, application of bleeder, and bagging ready for cure. Machine layup was not accomplished for all the graphite skins, and our goals for tape-laying efficiency were not attained for three reasons:

1. Poor tape quality

2. Carrier paper too thin and not tough enough

3. Machine inadequacies

TAPE QUALITY

Prior to receipt of the initial incremental shipment of graphite tape, training operations on the tape-laying equipment were in progress using leftover tape of lower quality than that to be employed in spoiler production. Upon receipt of the initial tape shipment (Union Carbide Thornel 300/2544), a set of four upper spoiler skins (65-76327-8) was laid up on the layup tool. The layup was judged to be of superior quality upon Engineering inspection. The tape material also appeared to be of superior quality when compared with tape utilized on the Boeing research spoiler program.

The completed skin layup proceeded unsuccessfully through the autoclave curing cycle, with the failure attributed to the following:

- The parting film between the skin layup and the tool was inadvertently damaged by cleaning solvents, causing the layup to adhere to the tool.

- The vendor cure cycle used on the layup resulted in excessive bleedout of the resin from the layup.

A revision of the handling procedures in the layup process eliminated the first problem. Coordination with Union Carbide resolved the cure-cycle discrepancy. A revision to the cure cycle was developed by Engineering, and a test run was made to ensure that the parts would release from the tool if the resin content was correct and the release agent coating on the tool was adequate. The next set of four -5 lower skins proved to be acceptable.

A single "pilot" skin was laid up from the second tape shipment (Hercules) despite the fact that an Engineering rejection had been made on this shipment for quality reasons. This pilot skin was cured and successfully released from the layup tool, demonstrating a successful solution to the sticking problem of the first layup. Tape quality problems appeared when attempts were made to use the Hercules production graphite tape (as opposed to the evaluation sample) for skin layups. Gaps and width variations far in excess of our specified allowances were numerous and random throughout the shipment. Approximately 30 m (100 ft) of tape was removed from each of several reels. Engineering inspection indicated that the material was not acceptable, and the decision was made to return it to the vendor. Figures 6 and 7 are representative of these variations.

The initial shipment of Narmco tape also showed out-of-tolerance gaps and width variations, but to a lesser extent than the Hercules tape. The tape also had shreds of paper left on the carrier paper edges as a result of the slitting operation. The shreds had to be removed from between the edges of the laid tape strands to prevent their inclusion in the laminate.

A manufacturing representative was dispatched to the Hercules and Narmco plants to show them the unacceptable defects, explore the reasons for them, and assess the probability of resolving the problems. Both vendors assured the representative that they could and would meet Boeing requirements. Tape subsequently received from Narmco was considered by the shop personnel to be the best received from any source to date. Several layups were made by machine without requiring any significant repair for gap or overlap.

In summary, the following manufacturing assessment of the skin layup experiences was made concerning the several prepreg materials used in this program.

- *Union Carbide T300/2544*. Tape quality was generally good with respect to dimensional control, fiber alignment, and control of internal variations. Tack control, and variation of tack from batch to batch, appeared to be the major

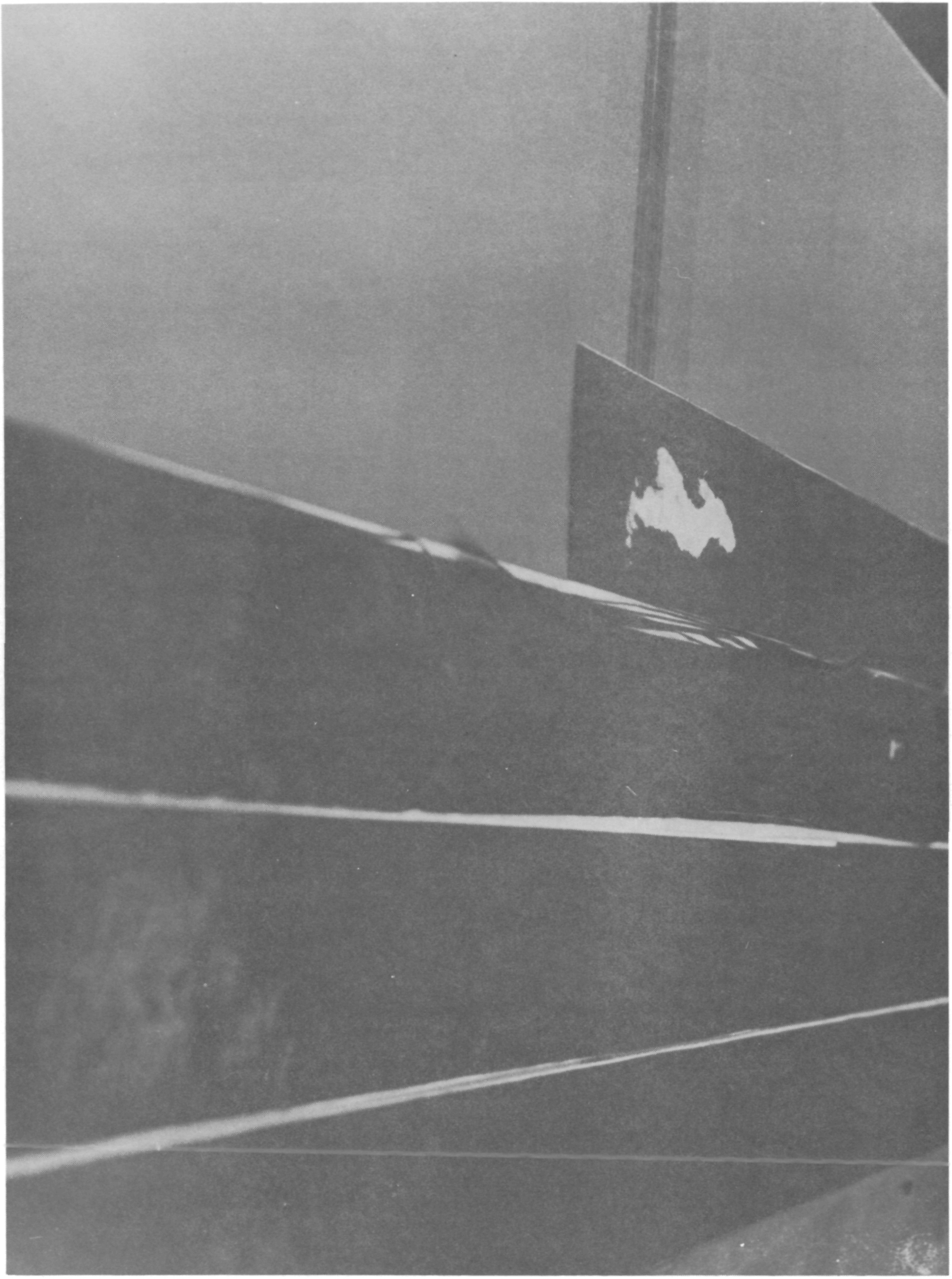


Figure 6.—Graphite Prepreg Tape Samples—Representative Rejectable Conditions

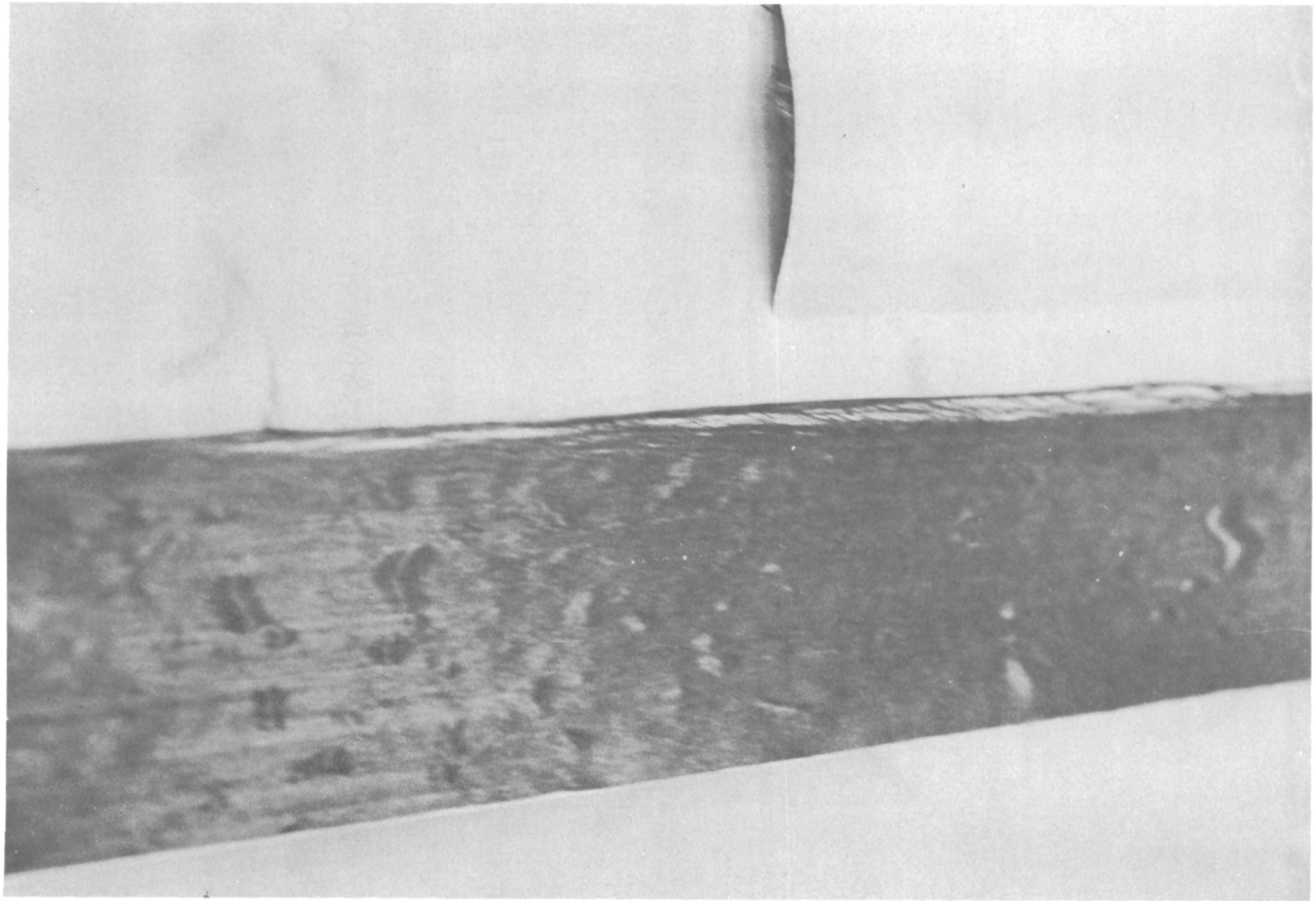


Figure 7.—Graphite Prepreg Tape Samples—Representative Rejectable Conditions

problems. When the tack became low, the mechanical layup had to be followed with substantial handwork to properly position and press down the tape edges.

- *Narmco T300/5209*. Since the early quality problems with the Narmco prepreg, the Narmco prepreg quality has shown significant improvement. Dimensional control, straightness of tows and fibers, and tack have been evaluated as satisfactory or better. The tape performs well in the layup machine and several layups have been completed with virtually no handwork.

- *Hercules AS/3501*. To correct the significant tape quality problems discussed previously, the vendor supplied a representative 4.5-kg (10-lb) lot for evaluation by Auburn Manufacturing. The evaluation was conducted on the tape-laying machine, and a considerable improvement in tape quality was noted in the set of skins made from this lot. However, subsequent shipments received in May and June showed some deterioration in quality, notably in tack and tow alignment control. The most severe examples of the lack of tow alignment are voids produced by "wandering" tows, examples of which are shown in figure 8, where segments were cut from Hercules run 411. Gap defects, such as those shown in figure 9, occurred with less frequency and were easier to detect and remove. The most severe problem, however, was the low tack level.

  The tape systems that used solvated resin impregnation tended to be considerably drier on the exposed surface (the surface of the tape that would normally be applied to the tool or previously applied ply) than they were on the surface next to the carrier. This meant that the graphite tape stuck (tacked) to its carrier much harder than it did to the tool or previously laid ply. In many instances it was virtually impossible to remove the carrier from the laid tape without dislodging the tape from its assigned location. Many man-hours could have been saved if the tape would have released from the carrier more easily or if the tack of the previously laid ply (or tool surface in the case of the first ply) could have been considerably increased. Adhesive primer was evaluated as a tack improver; however, it dried rapidly and did not solve the problem.

Considerable effort was expended on this program to obtain prepreg tape quality significantly better than that available from the industry prior to implementation of this program. The need for improved tape quality to permit the use of automatic tape-laying equipment has been satisfactorily demonstrated. Continued insistence on the established level of tape quality required will be beneficial to future composite production programs.

MACHINE LAYUP

Because the tape carrier plays a most important role in attempts to mechanically lay the tape, a concept of tape laying was developed around the premise that we would be able to cut the tape consistently without cutting the carrier. On small test panels, this met with some success and encouragement. On the production parts, however, we were unsuccessful. A check of the carrier paper used on the test tapes showed the paper to be 0.14 mm (0.0055 in.) thick (average) and highly resistant to cutting. The paper on the

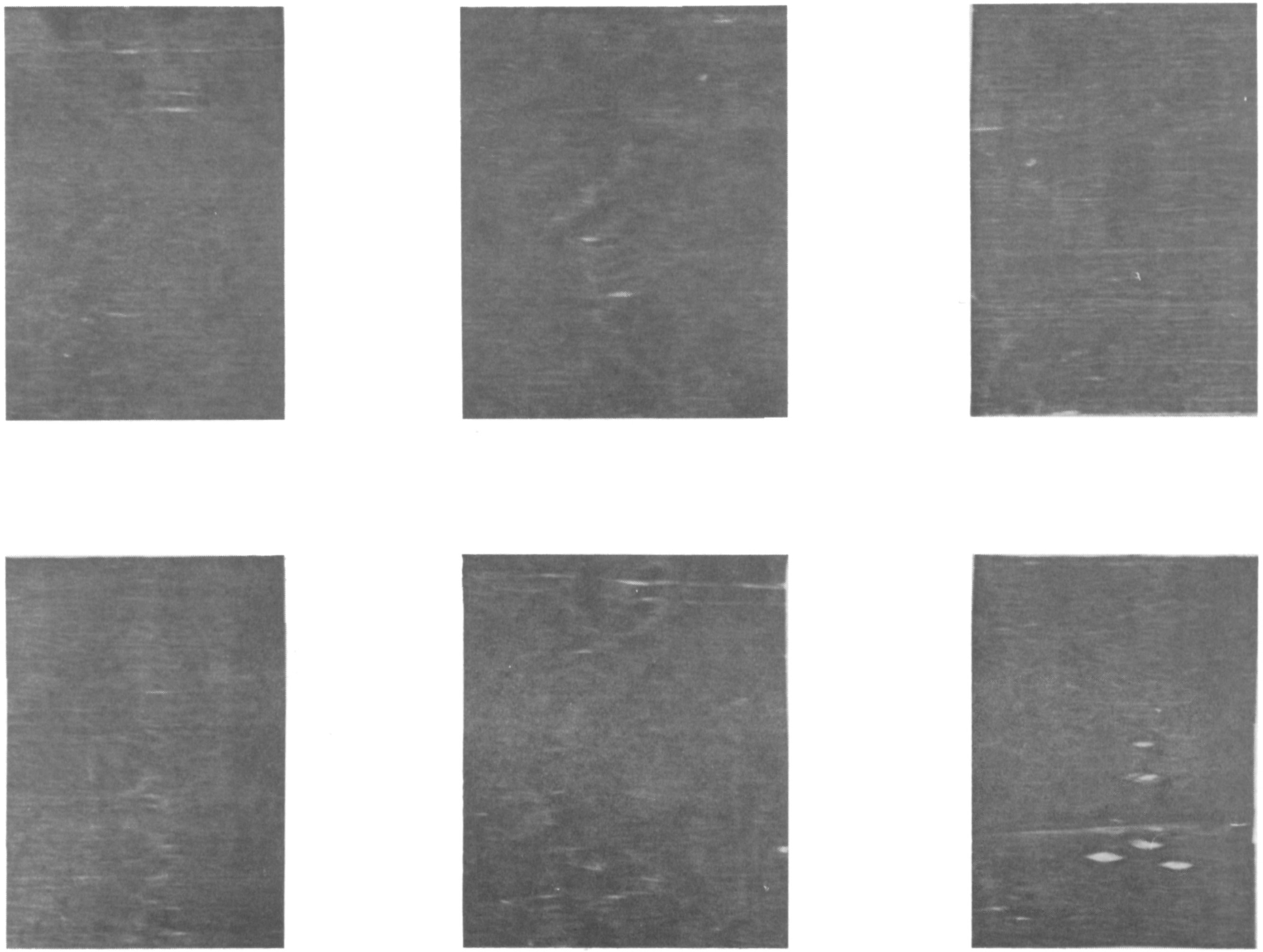


Figure 8.—Voids Due to Lack of Tow Alignment

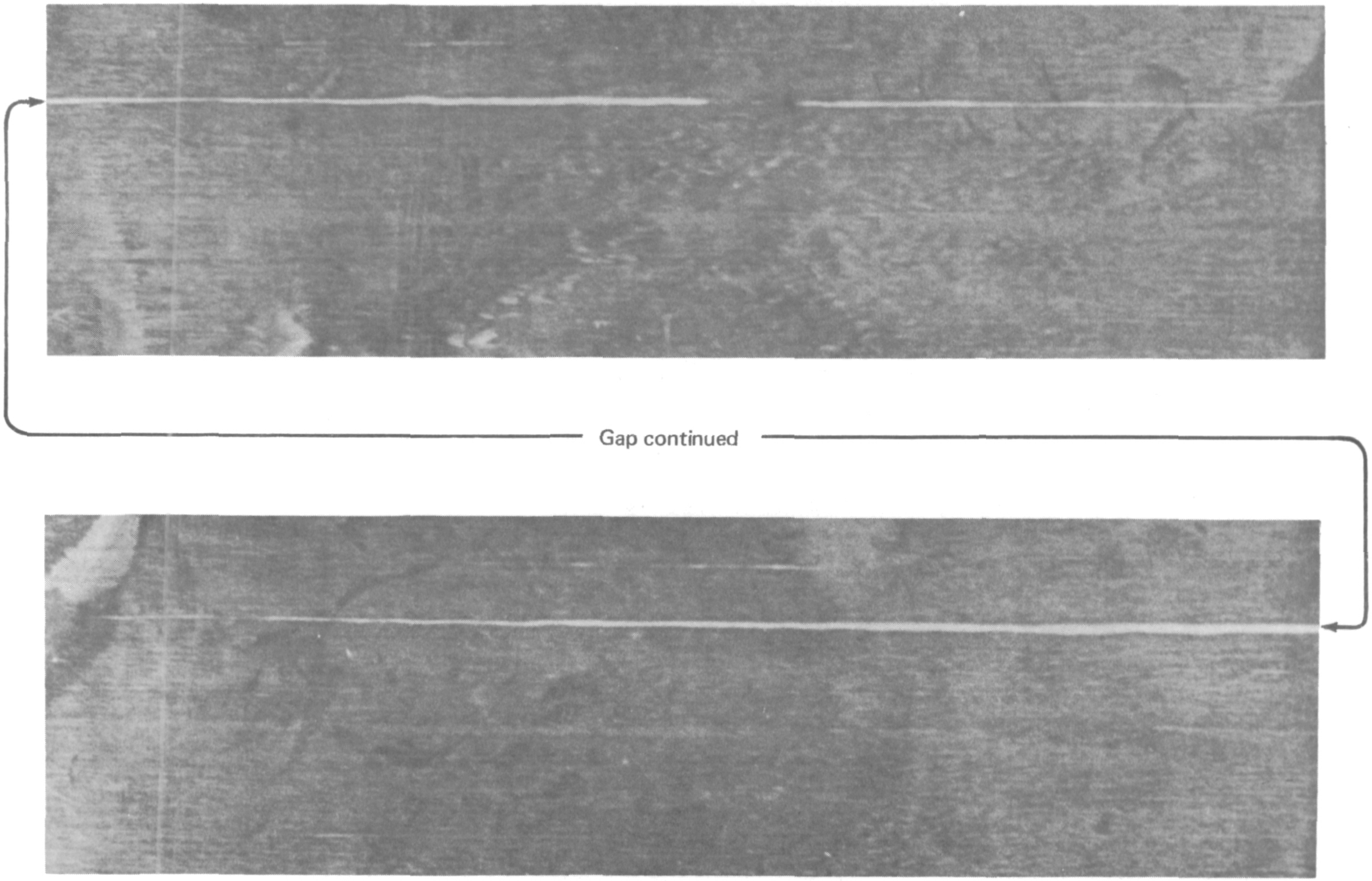


Figure 9.—Gap Defect Example

production tapes was all in the 0.089 to 0.102 mm (0.0035 to 0.004 in.) range. We were unable to locate heavier paper available in time to support the program. The tape was therefore cut by hand even when it was laid by machine. Even under these conditions, the tape could be laid faster by machine than it could by hand if the tack was at all reasonable.

One rather significant problem was that of maintaining a parting surface on the steel BAJ for the upper surface skins. Unless the parting agent (Frekote 33) was freshly applied before each layup, the skins tended to stick (bond) to the tool surface. Several skins were irreparably damaged this way. There was no serious sticking of the skins to the epoxy-plastic contoured tool for the lower skins. At the conclusion of the contract effort, however, the gel coat on the plastic tool was breaking down and would have soon required major rework.

The tape-laying machine had two notable deficiencies, as illustrated in figure 10. First, it would not lay tape to the contours involved because the delivery head did not maintain normalcy to the contour. Future machines should sense contour and rotate the head on the Z-axis to keep it perpendicular to the average contour. The other problem with the machine was that the centerline of the delivery head was located 140 mm (5.5 in.) from the centerline of the vertical motion way. This eccentricity caused wide variations in the actual pressure on the tape at delivery. It also permitted pressure variation across the width of the tape because of cantilever deflection. Future machines must avoid this problem also.

During the program, requirements were established for future machine and tape improvement. These have been coordinated with prepreg tape manufacturers and incorporated into designs for an improved tape layup head.

SKIN PROCESSING SEQUENCE

The following procedure was used to fabricate the upper graphite skin laminate (65-76327-8, -9, and -10).

- Set up the steel tool (XLM 65-76318-6) (fig. 11) on the table of the tape laydown machine.

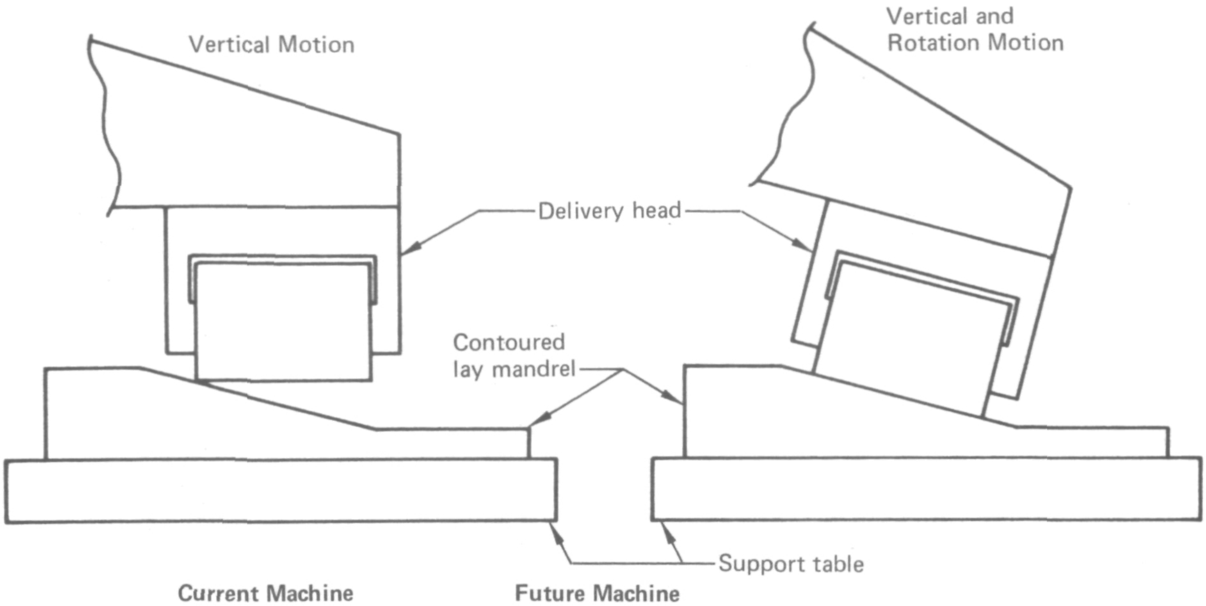
    1. Clean the working face of the tool with MEK and dry for a minimum of 15 minutes at 288 to 302 K (70^0 to 85^0 F).

    2. Apply Frekote 33 parting agent to the tool.

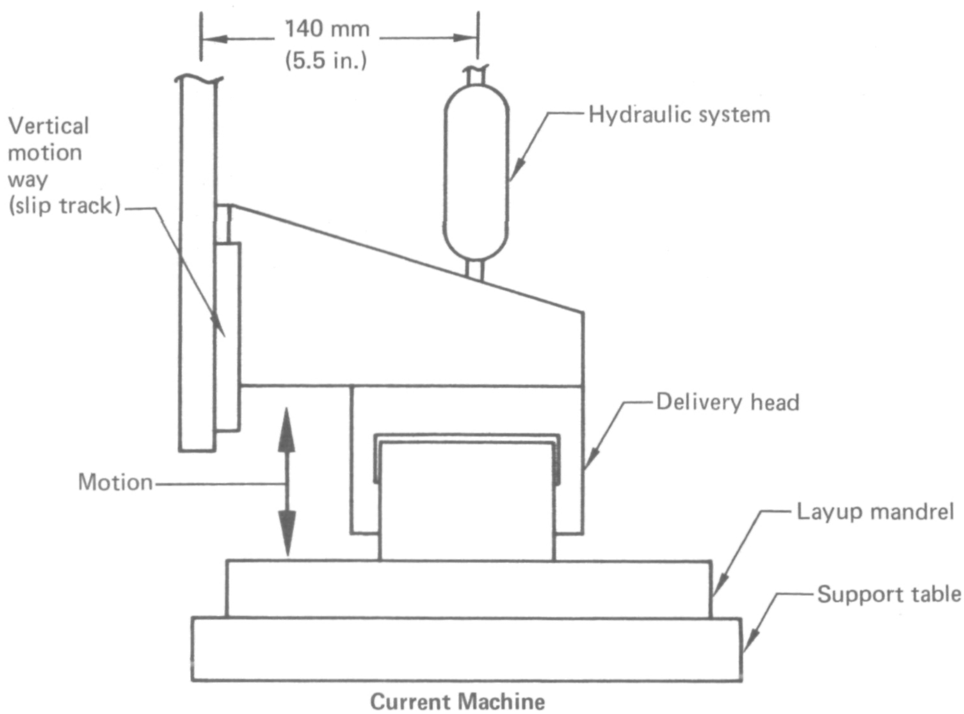
    3. Apply a thin coat of BMS 5-51, type 1, adhesive primer to the tool surface to cover. Allow primer to air dry for 30 minutes at 288 to 302 K (70^0 to 85^0 F).

- Machine lay the skin laminates (figs. 12 and 13).

    1. Remove the total required amount of graphite-epoxy tape from cold storage and allow to warm at room temperature in the sealed package.



a. Contour Deficiency



b. Delivery Head Off-Axis Deficiency

Figure 10.—Tape-Laying Machine Deficiencies

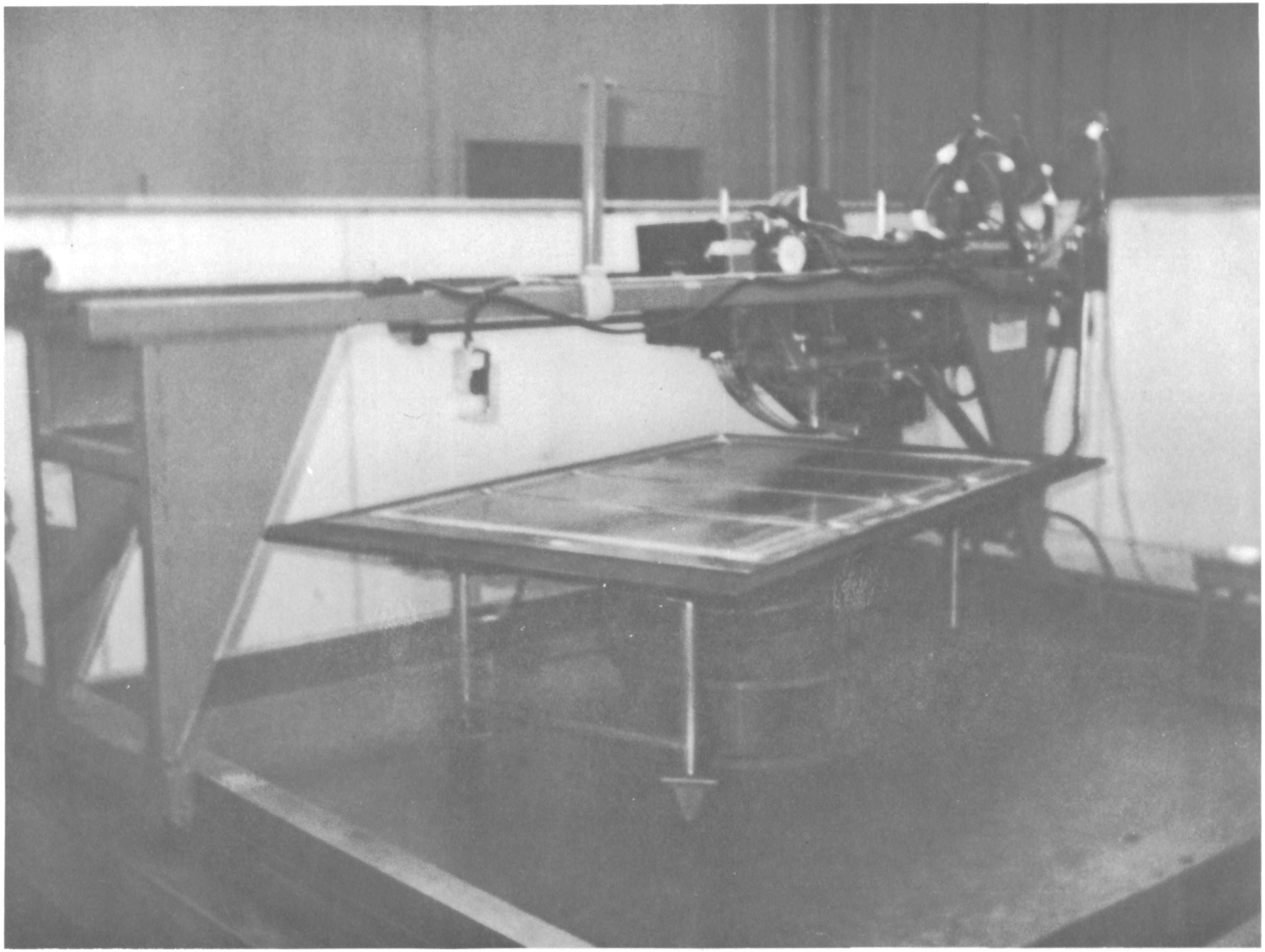


Figure 11.—Positioning of Steel Tool on Tape-Layup Machine

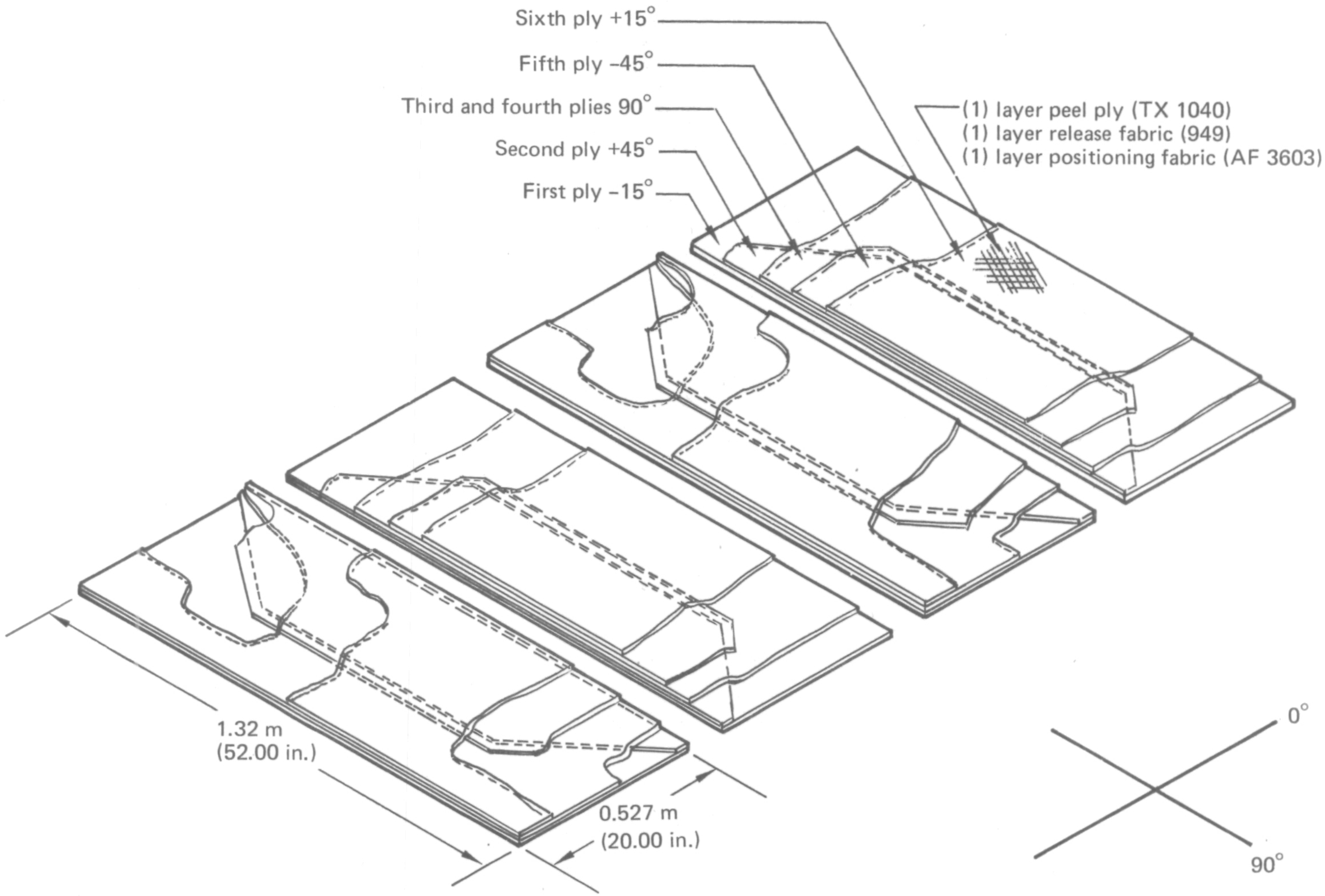


Figure 12.—Layup Sequence of Upper Surface Skin Laminate

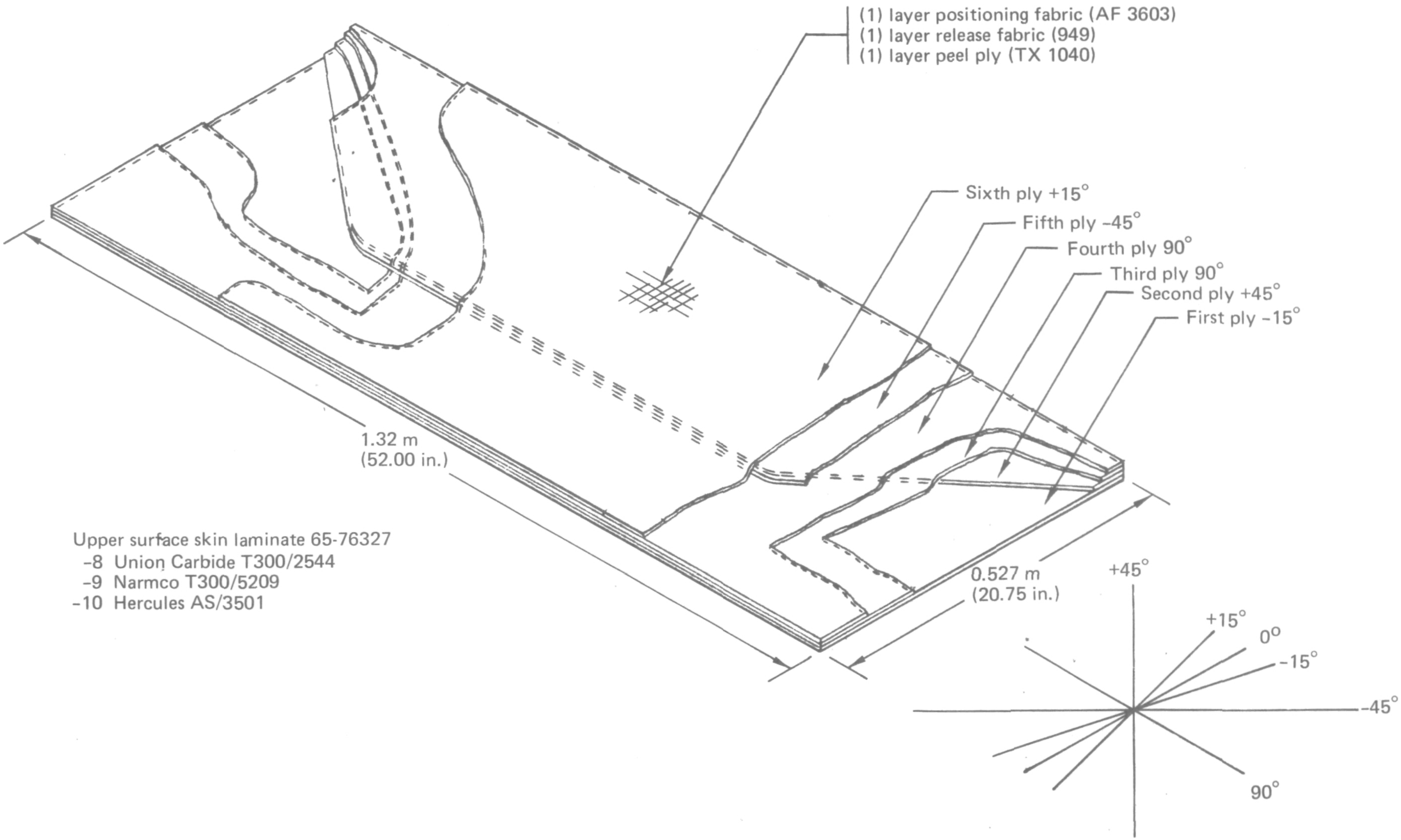


Figure 13.—Ply Orientation of Upper Surface Skin Laminate

2. Load the tape spool on tape machine and run checkout procedures.

3. Place the first-ply cutter template on the layup tool and secure with pins. Note: Also used to trim third, fourth, and sixth plies.

4. Lay down tape at -15^0 orientation until the first ply is completed (fig. 14).

5. Remove the trim material from the cutter template.

6. Place the second-ply cutter template onto the first-ply cutter template and secure with pins.

7. Lay down tape at $+45^0$ orientation until the second ply is completed (fig. 15).

8. Remove the second-ply cutter template and trim material.

9. Lay down tape at 90^0 orientation until the third ply is completed.

10. Remove the trim material from the cutter template.

11. Lay down tape at 90^0 orientation until the fourth ply is completed (fig. 16).

12. Remove the trim material from the cutter template.

13. Place the fifth-ply cutter template onto the first-ply cutter template and secure with pins.

14. Lay down tape at -45^0 orientation until the fifth ply is completed.

15. Remove the fifth-ply cutter template and trim material.

16. Lay down tape at $+45^0$ orientation until the sixth ply is completed.

17. Remove the cutter template from layup tool.

18. Remove the tool from tape laydown machine and place on work table.

19. Carefully solvent clean and wipe dry tool surface around laminate using care not to get solvent on laminate.

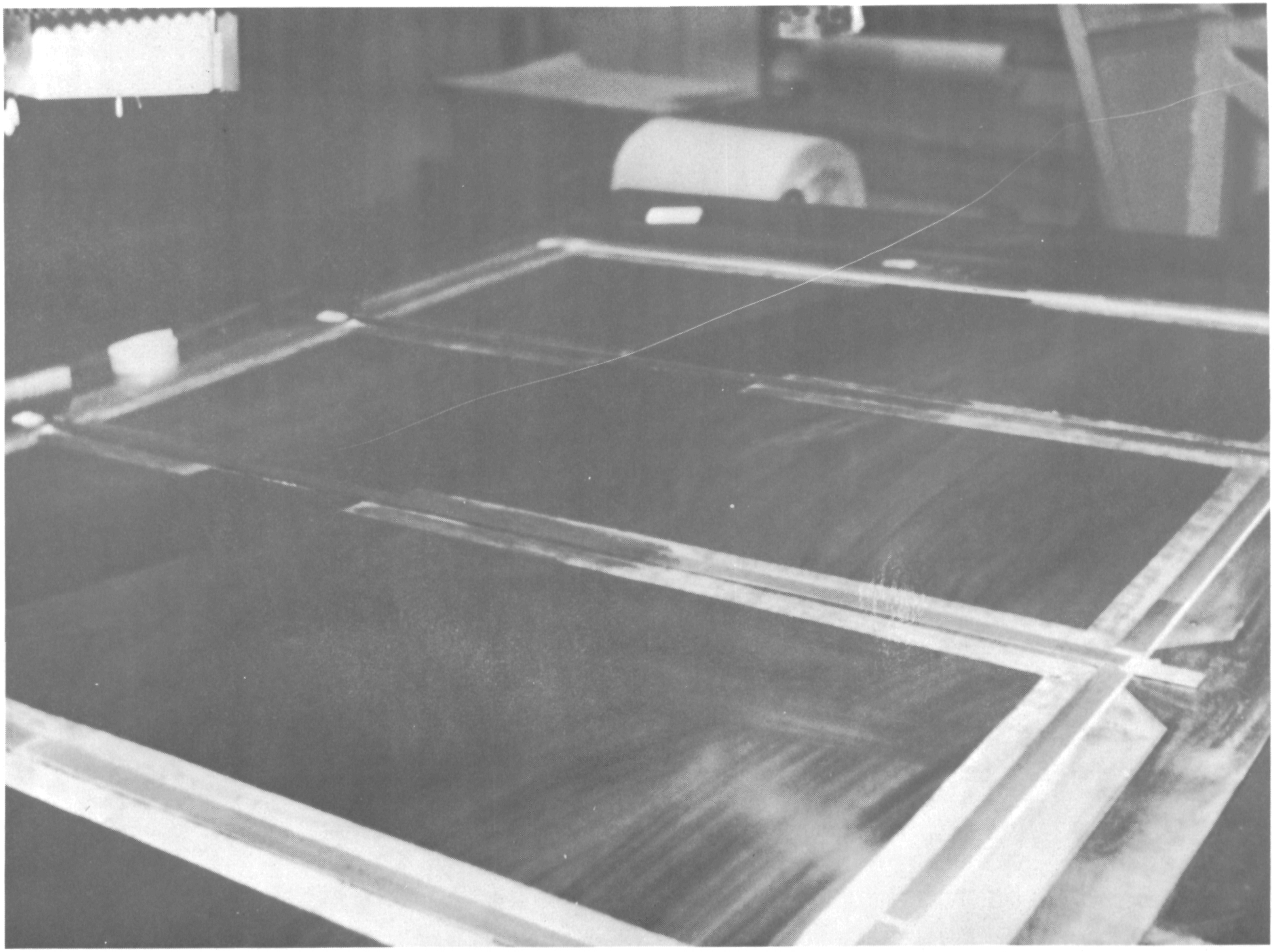


Figure 14.—Primed Tool and Laydown of First (-15°) Ply

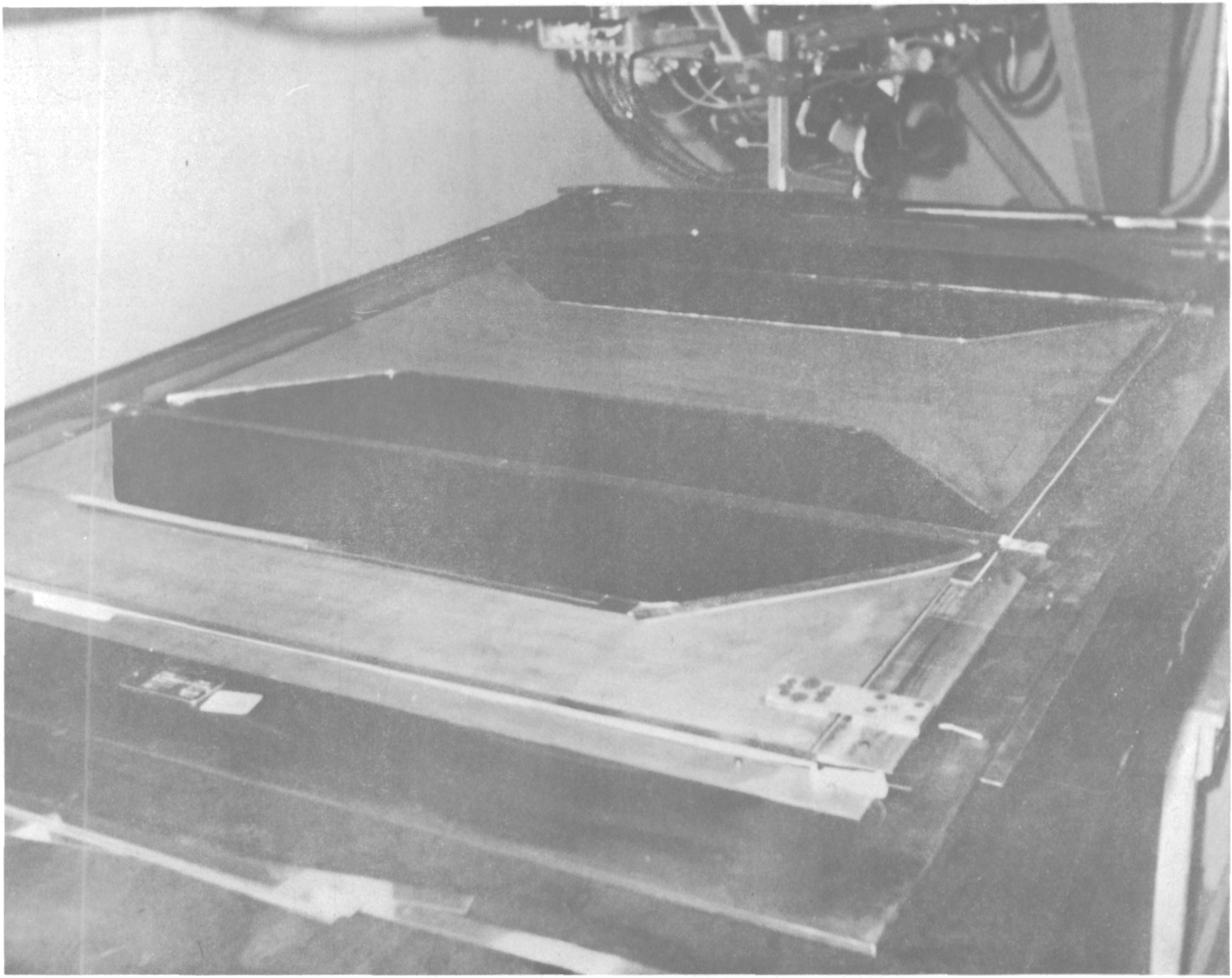


Figure 15.—Laydown of 45° Doubler Ply

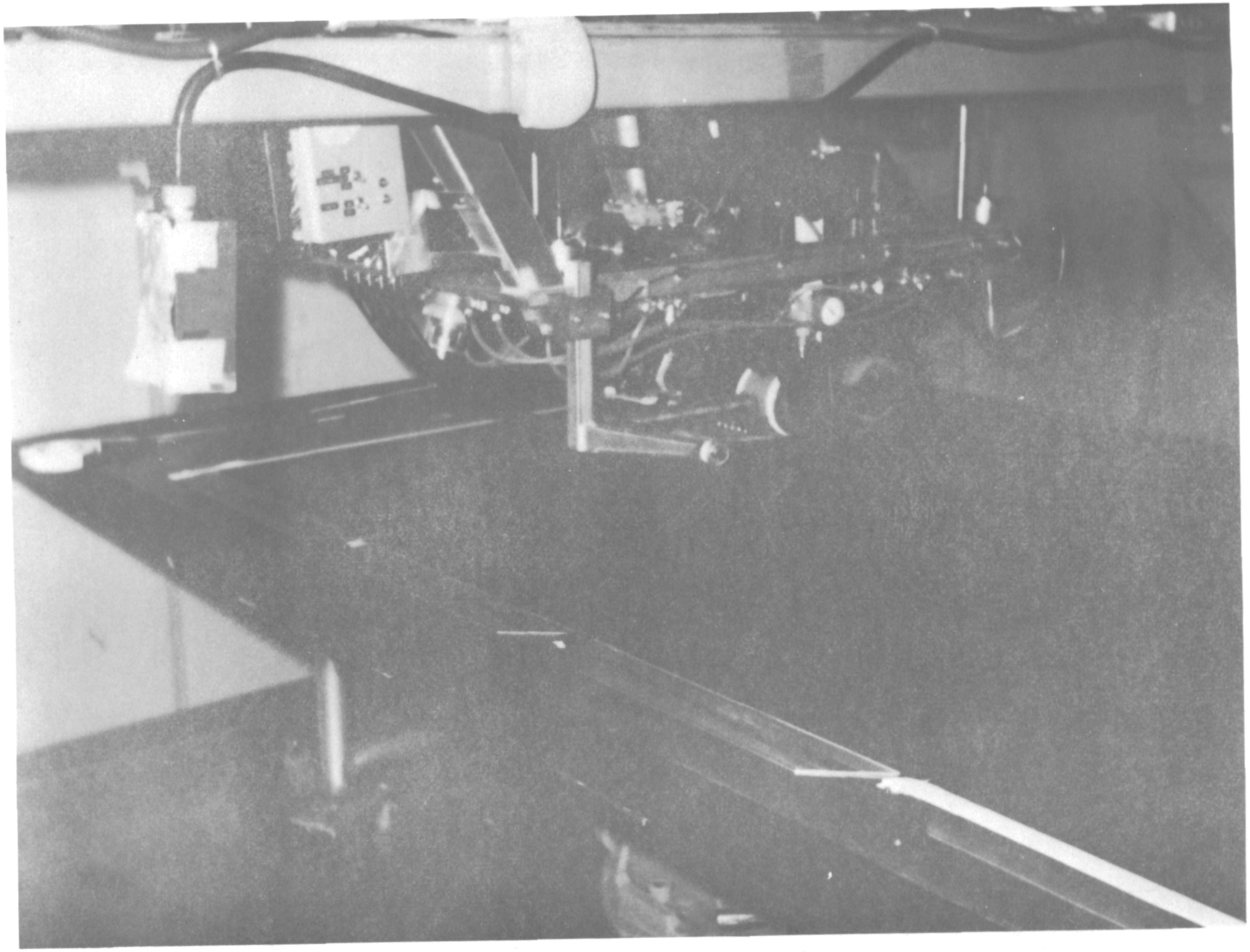


Figure 16.—Laydown of 90° Skin Ply

20. Make entries on tape recordings as follows:

Graphite-epoxy preimpregnated tape material

Supplier ______________________________

Lot Number ______________________________

Date of Manufacture ______________________________

Date Received ______________________________

Amount ______________ Ft/Yds ______________

In refrigerated storage date ______________________________

Amount removed ______________ Ft/Yds ______________

Amount remaining ______________ Ft/Yds ______________

EWA number ___725001___ Work Order ___68725___

Material removed by ______________________________

Repackaged by* ______________________________

*Note: If portion of graphite remains on tape spool, seal in a plastic bag and store in refrigerator for subsequent usage. Affix date on package and return to refrigerator.

- Apply vacuum bag (fig. 17).

1. Apply corprene material (wrapped with FEP film) all around periphery of laminate. Butt against edge but do not overlap. Secure with nylon tape. Note: Edge bleeding of laminate skin is not permitted.

2. Insert thermocouples to edge of corprene. Secure with teflon tape.

3. Apply vacuum bag sealing tape all around tool face. Apply tape over and under the thermocouple leads.

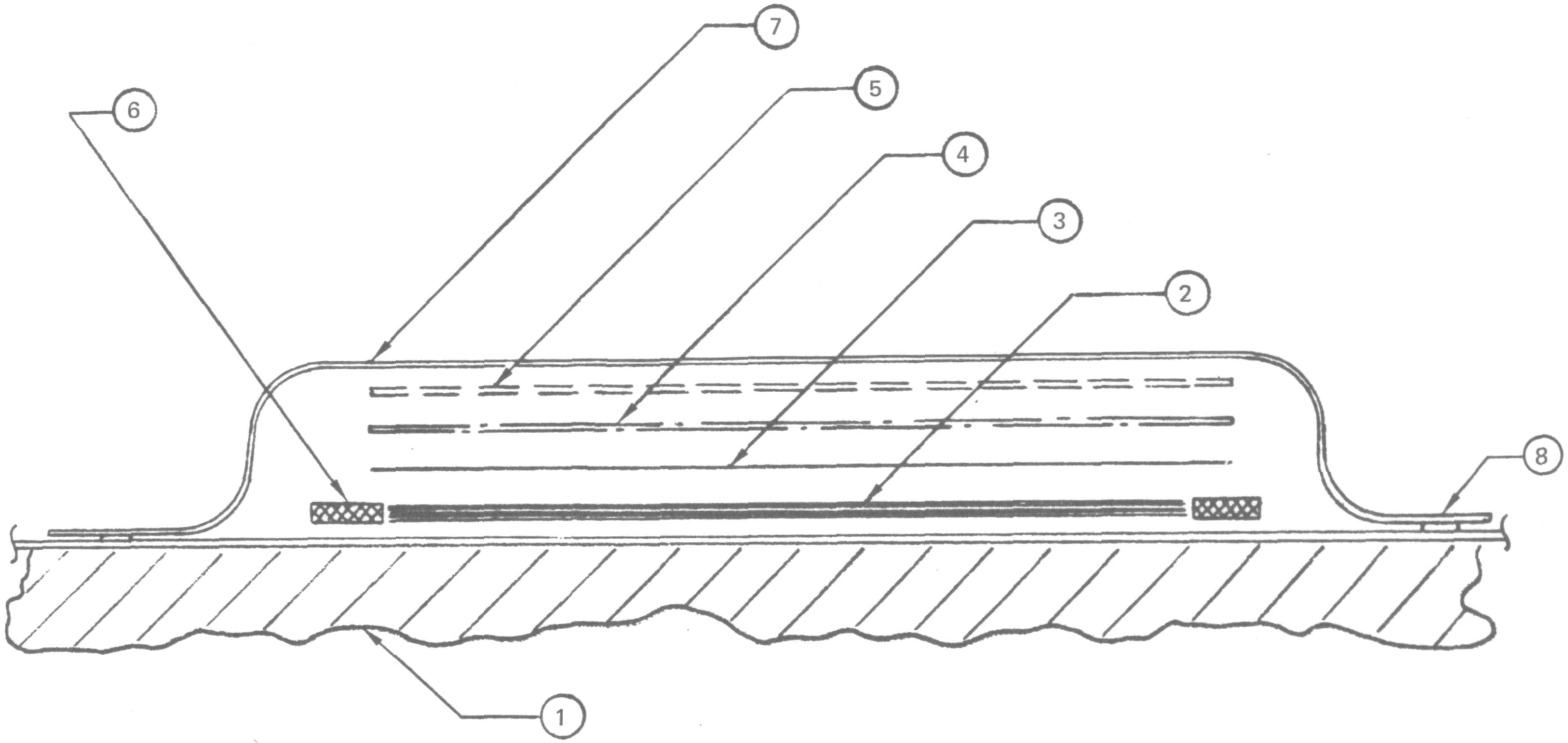
4. Apply one layer of positioning fabric (3M, AF 3603) to surface of layup.

5. Apply one layer of nylon peel ply (Ferro Corp./Cordo Division style 949) to surface of layup.

6. Apply one layer of bleeder paper (Moehburg Paper CW 1850) to surface of layup.

7. Apply a diaphragm cover of nylon vacuum bag film (Richmond Corp. HS-6262) over entire tool face. Pull wrinkle free and impress into sealing tape.

   a. Attach a vacuum connection. Slowly pull a vacuum (508 mm (20 in.) of mercury minimum) to the interior of the vacuum bag.



1. Layup mold
2. Graphite-epoxy layup
3. 3M AF 3603 positioning fabric (one layer)
4. Ferro/Cordo Div. 949 nylon peel ply (one layer)
5. Moehburg CW 1850 bleeder paper (two layers)
6. Western Gasket and Packing DK-153 corprene dam
7. Richmond Corp. HS-6262 nylon vacuum bag
8. Schnee-Morehead 5144 vacuum bag sealing tape

Figure 17.—Bagging Sequence

b. As the air is evacuated, make the bag conform to the shape of the part and keep wrinkles to a minimum. Check for leaks by disconnecting and plugging vacuum line.

c. The vacuum gage reading must not drop more than 127 mm (5 in.) of mercury in 1 minute.

- Cure the laminate per the autoclave cycle developed in cooperation with the supplier (fig. 18).

- Remove vacuum bag materials and inspect laminate.

- Visually locate tool onto skin and shape outer periphery to net configuration. Omit all holes–accomplished on assembly.

The procedure used to produce the lower graphite skin laminate (65-76327-5, -6, and -7) was the same as for upper laminate except for laydown of skin plies. The machine laydown operation is given below. Ply orientation is illustrated in figure 19. Note: First ply (-15^0) per drawing becomes eighth ply ($+15^0$) OML surface when inverted 180^0 on assembly.

1. Remove the total required amount of graphite-epoxy tape from cold storage and allow to warm at room temperature in the sealed package.

2. Load the tape spool on tape machine and run checkout procedures.

3. Place the outer-periphery-ply cutter templates on the layup tool and secure with pins. Note: Used to trim third, fourth, and eighth plies.

4. Working from eighth ply up (reverse orientation as this ply becomes OML), lay down tape at -15^0 orientation until the eighth ply is completed.

5. Remove the trim material from the cutter templates.

6. Orient layup, position head, and take one pass at a 90^0 orientation to generate seventh ply.

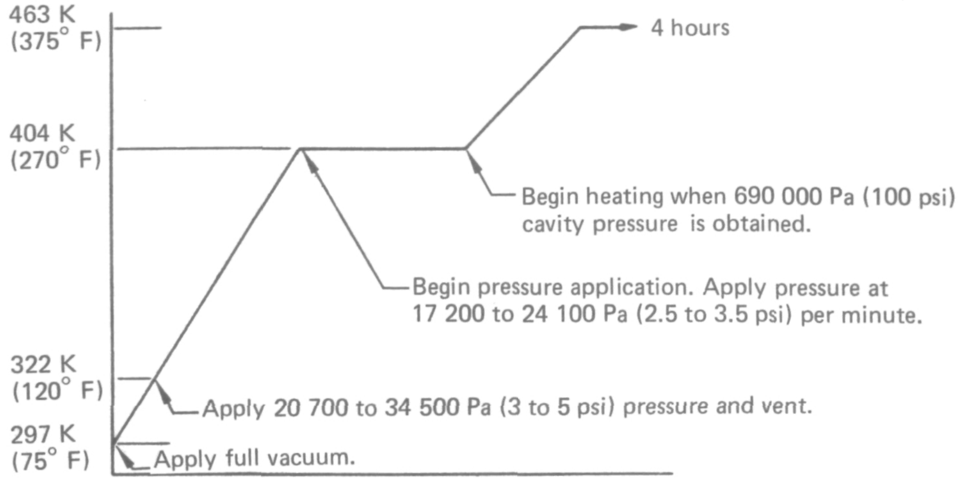
7. Index head to position and take one pass at a 90^0 orientation to generate sixth ply.

8. Place the doubler-ply templates onto the previously loaded templates and secure with pins.

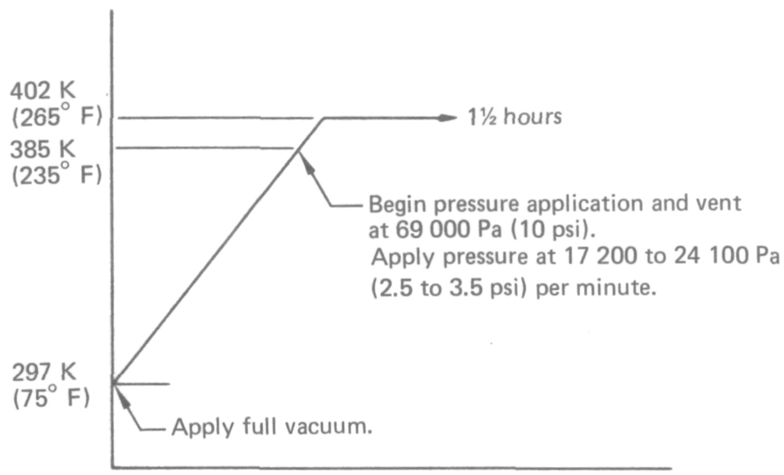
9. Orient layup and lay down tape at $+45^0$ orientation until the fifth ply is completed.

10. Remove the doubler-ply cutter templates and the trim material.

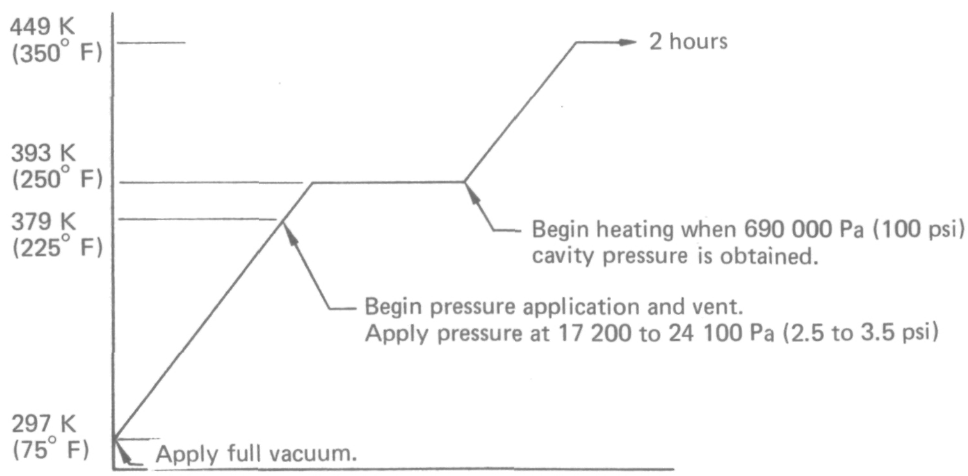
11. Orient layup and lay down tape at 90^0 orientation until the fourth ply is completed.



a. **Union Carbide T300/2544**



b. **Narmco T300/5209**



c. **Hercules AS/3501**

Figure 18.—Laminate Cure Cycle

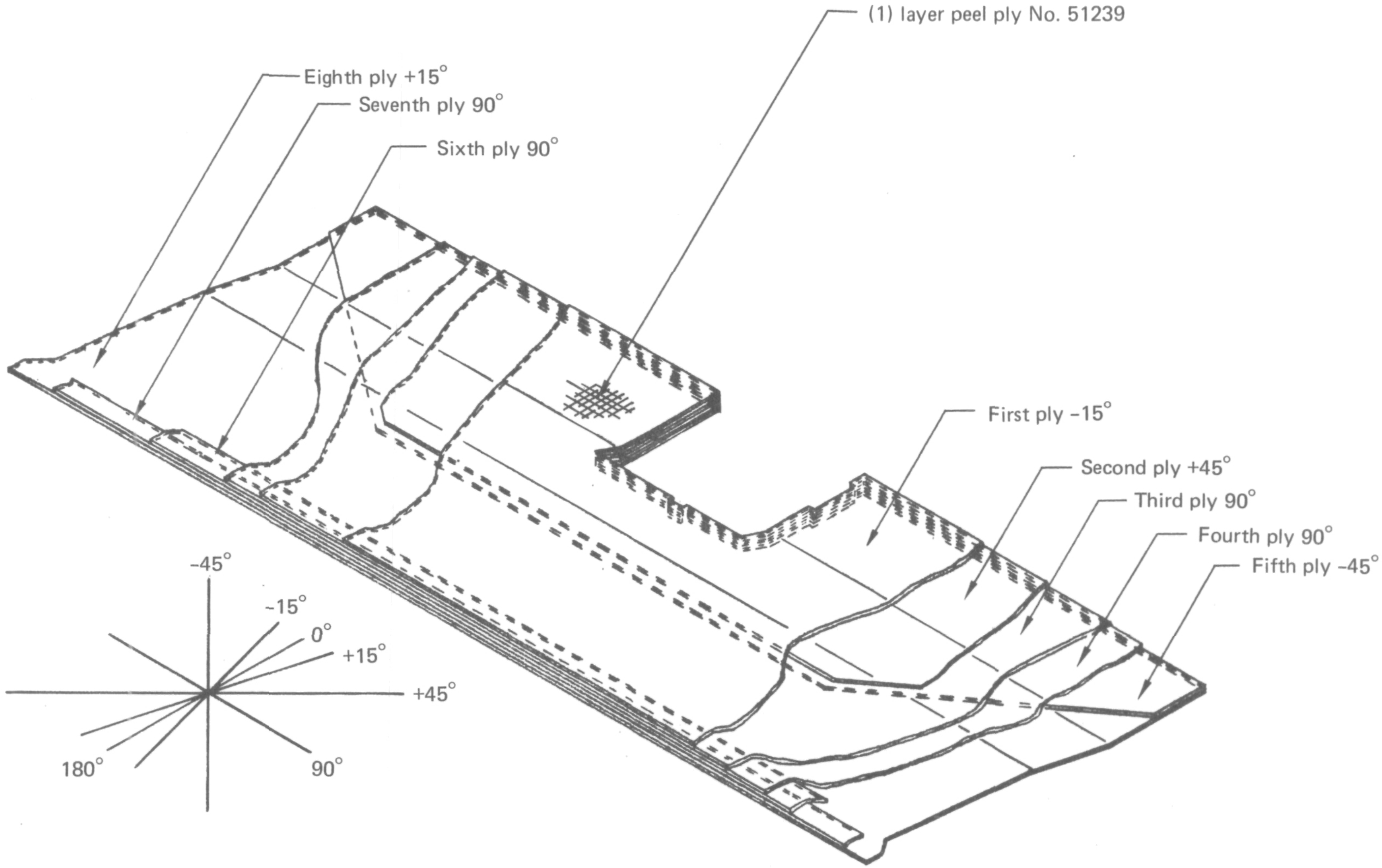


Figure 19.—Ply Orientation of Lower Surface Skin Laminate

12. Remove the trim material from the cutter templates and lay down tape at 90° orientation until the third ply is completed.

13. Remove the trim material from cutter templates and place the doubler-ply cutter templates on outer-periphery-ply cutter templates; secure with pins.

14 Orient layup and lay down tape at -15° orientation until the second ply is completed.

15. Remove the doubler-ply cutter templates and the trim material.

16. Orient layup and lay down tape at +15° orientation until the first ply is completed (this surface common to core).

Due to problems with the tape machine and tape quality, mechanized layup of the skin laminates could not be accomplished consistently. Most of the skins were hand laid using the processing sequence described previously.

END RIB FABRICATION

The following procedure was used to produce the end ribs (fig. 20).

- Prepare XLM-3 layup tool.
- Lay up 5 plies of type 181 fiberglass-epoxy (BMS 8-79) for -3 and -4 end ribs and 11 plies for -5 and -6 wedge strips.
- Vacuum bag and cure at 393 K (250° F) and 345 000 Pa (50 psi).
- Trim ribs and wedges, and autoclave bond wedges onto ribs.
- Machine rout tapes in wedge strip to blend with end rib.

SPOILER ASSEMBLY

The use of graphite skins instead of aluminum skins was the principal difference between the program spoilers and conventional 737 spoilers. The only departure from conventional spoiler fabrication procedures was that both graphite skins were bonded to the core-fitting-spar-end rib subassembly in a single operation. This was done to avoid the envisioned problems that would result when a zero expansion graphite skin was bonded at 393 K (250° F) to one side of an aluminum core-fitting-spar-end rib subassembly.

The standard procedure of bonding one skin simultaneously with bonding the core, spar, etc. fixes the location of the end ribs. Leaving the skin off allowed the adhesively stabilized core to shrink dimensionally during vapor degreasing and bake-dry of the machined spar-core-etc. subassembly. A clamp-on rod was successfully used to maintain the proper dimension at the trailing edge (between the end ribs) during the operations. Bonding the skins simultaneously provided essentially warp-free assemblies.

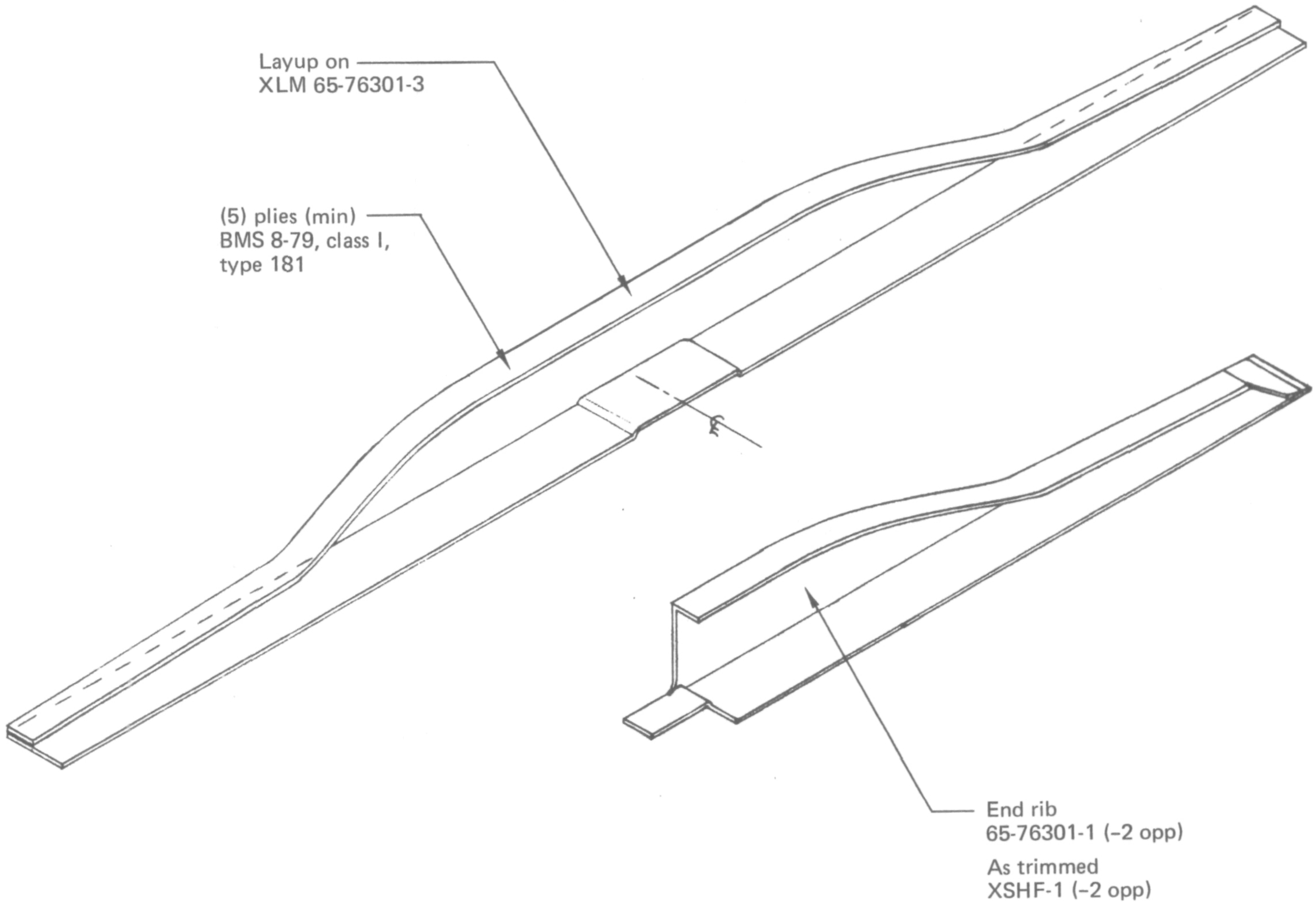


Figure 20.—End Rib Fabrication Sequence

The assembly of the spoiler was done in four stages:

- Mechanical assembly to make part number 65-76327-9004 frame
- First-stage bond to make 65-76327-4 honeycomb assembly
- Second-stage bond for assembly of honeycomb assembly, doubler, and graphite skins
- Third-stage assembly of phenolic rub strip, fillers, grounding wire and bolt, bearings, and seals

FRAME ASSEMBLY

Mechanical assembly of the frame (fig. 21) was accomplished as follows.

- Clean and prepare XAJ 65-76318-3.
    1. Place locating fixtures on base plate as required for locating and holding details on XAJ.
    2. Apply MEK to the working faces of tool and wipe dry with clean cheesecloth.
- Locate and load the fitting, channels, and ribs.
- Drill fastener location, and clean and deburr holes.
- Rivet details, inspect, and protective wrap (fig. 22).

FIRST-STAGE BOND

Core bond assembly sequence (fig. 23) is given below.

- Prepare detail and assemble.
    1. Locate and load 65-76327-9004 frame assembly onto tool.
    2. Locate, load, prefit, and trim honeycomb core detail.
    3. Clean honeycomb core by vapor degreasing.
- Remove BMS 5-90, type 2, grade 100, class 250 foam adhesive and EA 9628 5- and 10-mil adhesive from storage. Let warm at room temperature (not less than 4 hours).
- Assemble and prepare for cure.
    1. Clean and prepare XBAJ 65-76318-3.

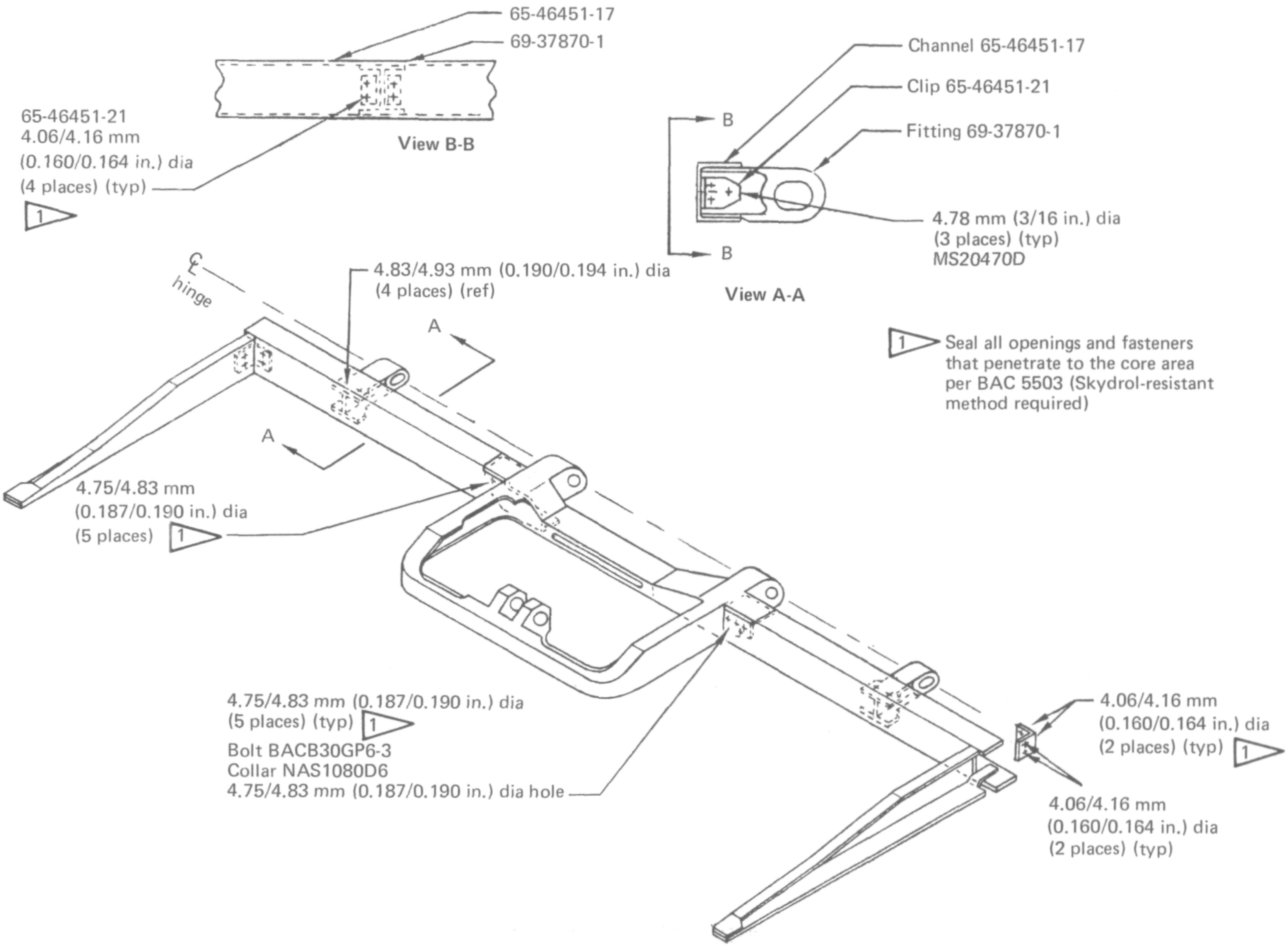


Figure 21.—Frame Assembly

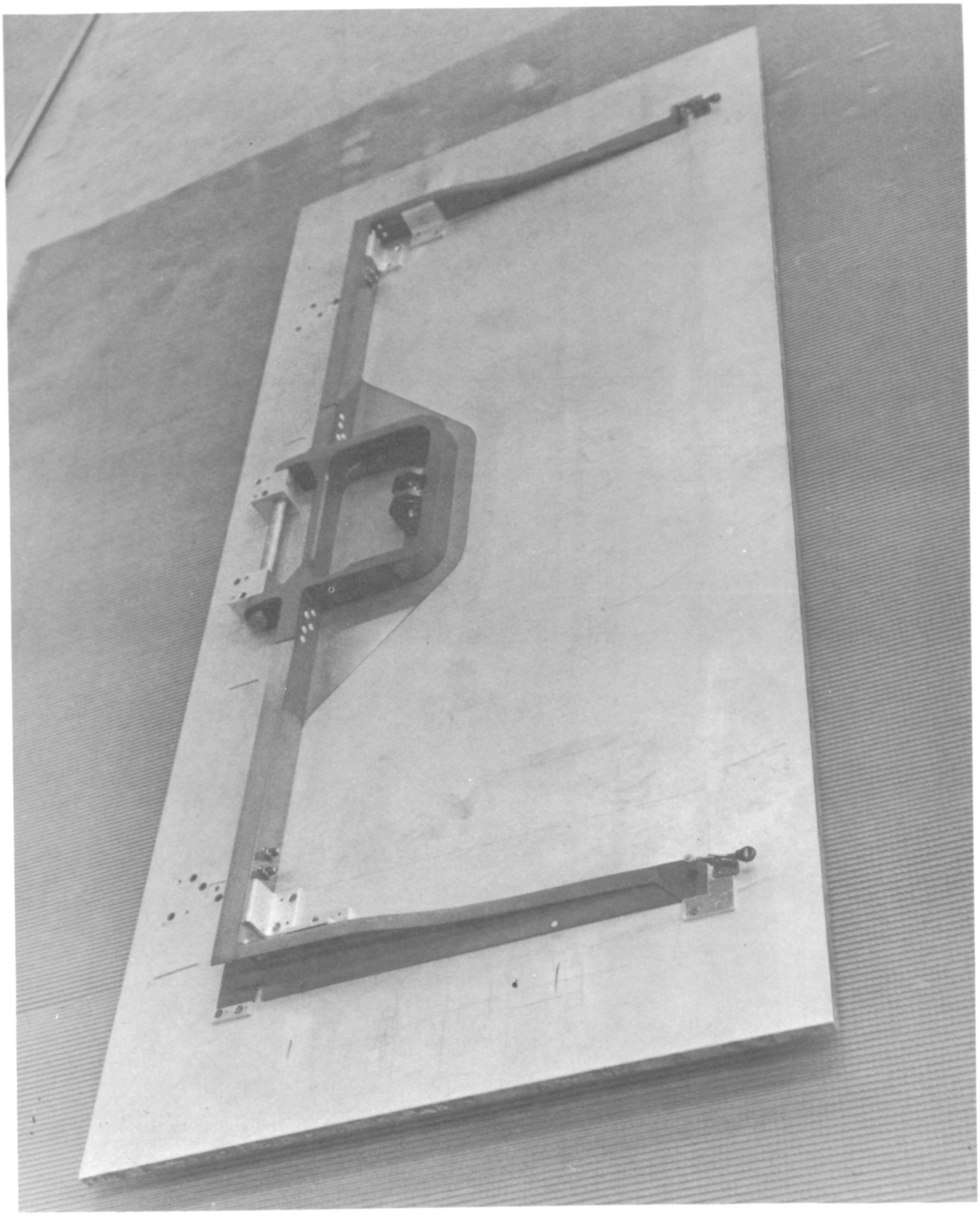


Figure 22.—Spoiler Frame Assembly Prior to Installation of Core

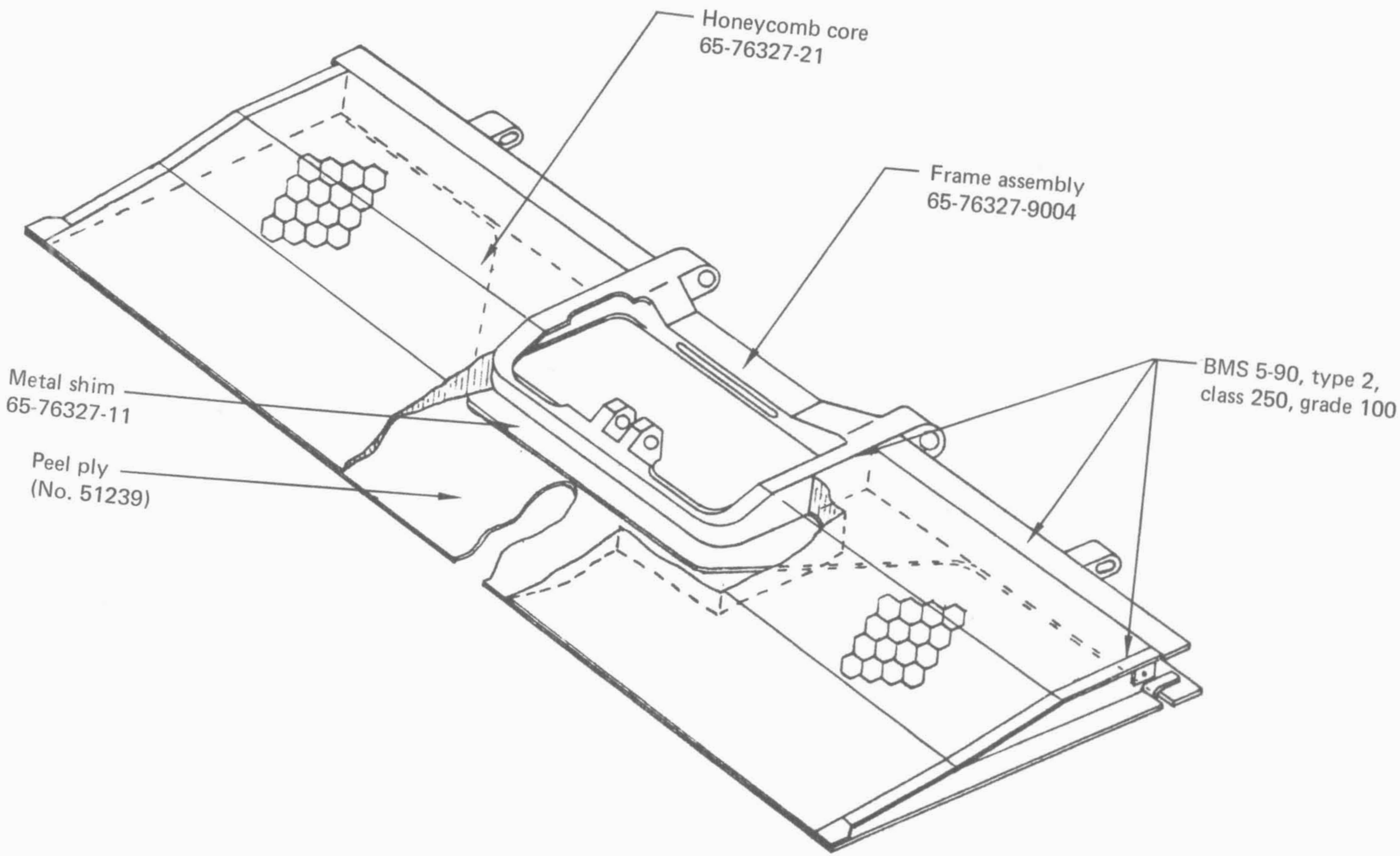


Figure 23.—Core Bond Assembly

2. Load the peel ply (No. 51239) onto full surface of tool first. Extend to outer periphery of end ribs and leading edge of channels.

3. Remove separator sheet from one side of EA 9628 5-mil adhesive and apply to complete surface of -11 metal shim and upper surface of each rib, channel, and center hinge fitting.

4. Apply BMS 5-90, type 2, class 250, grade 100 foam adhesive to faying surfaces (end ribs, leading-edge channels, hinge fitting) of the frame assembly and honeycomb core.

5. Install plug in cutout of hinge fitting. Secure the end ribs and aft edge with fairing bars. Cover buildup with tool fillers and 0.81-mm (0.032-in.) caul sheet.

6. Vacuum bag.

   a. Apply three layers of osnaberg bleeder cloth.

   b. Apply nylon vacuum bag.

- Machine lower surface to net configuration (fig. 24).

  1. Interchange the support bar of BMF 65-17348-3 with hinge point locator bar XBMF 65-76318-3 and load assembly.

  2. Machine lower surface of core to leading-edge channels, end ribs, and hinge fitting (fig. 25).

  3. Inspect final operation (fig. 26).

To stabilize the honeycomb core of the -4 assembly prior to bonding of the graphite skins, a film of EA 9628 adhesive is laid up on the flat surface of the unmachined honeycomb core and cured. This allows the machining operation to be performed without distorting the honeycomb cells. An additional advantage is that the stabilizing adhesive becomes a normal part of the second-stage bond assembly when an additional film of EA 9628 is applied to bond the graphite skins to the -4 honeycomb assembly.

The -4 assembly was modified with the addition of the -11 metal doubler, rather than installing the -11 doubler during the second-stage bond. This change allowed a more positive positioning of the -11 doubler plus additional honeycomb core stabilization for machining of the core.

SECOND-STAGE BOND

Honeycomb assembly, doubler, and graphite skin assembly procedure (fig. 27) was as follows.

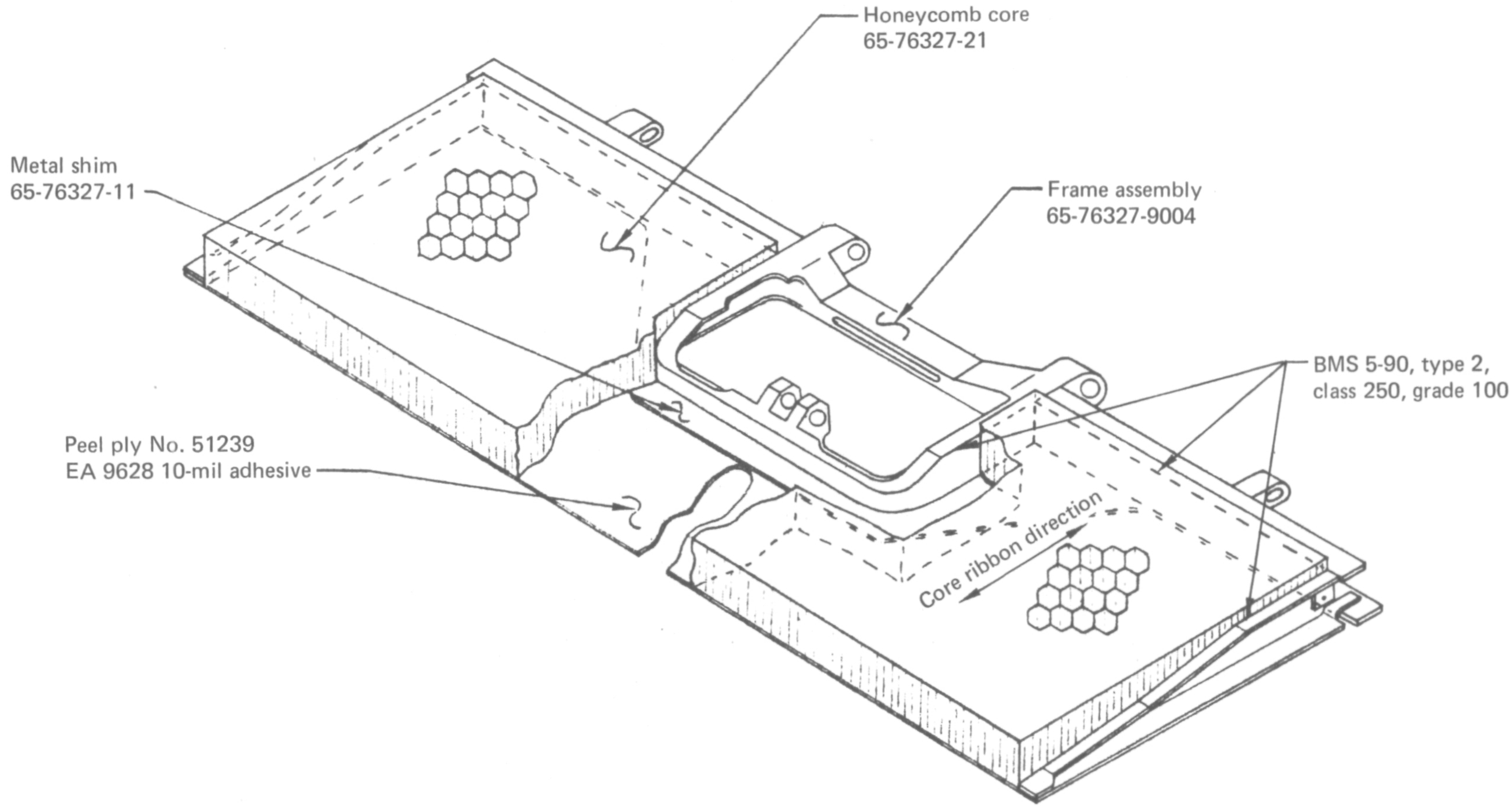


Figure 24.—Core Assembly Detail

Figure 25.—Machining of Honeycomb With a Valve Stem Cutter

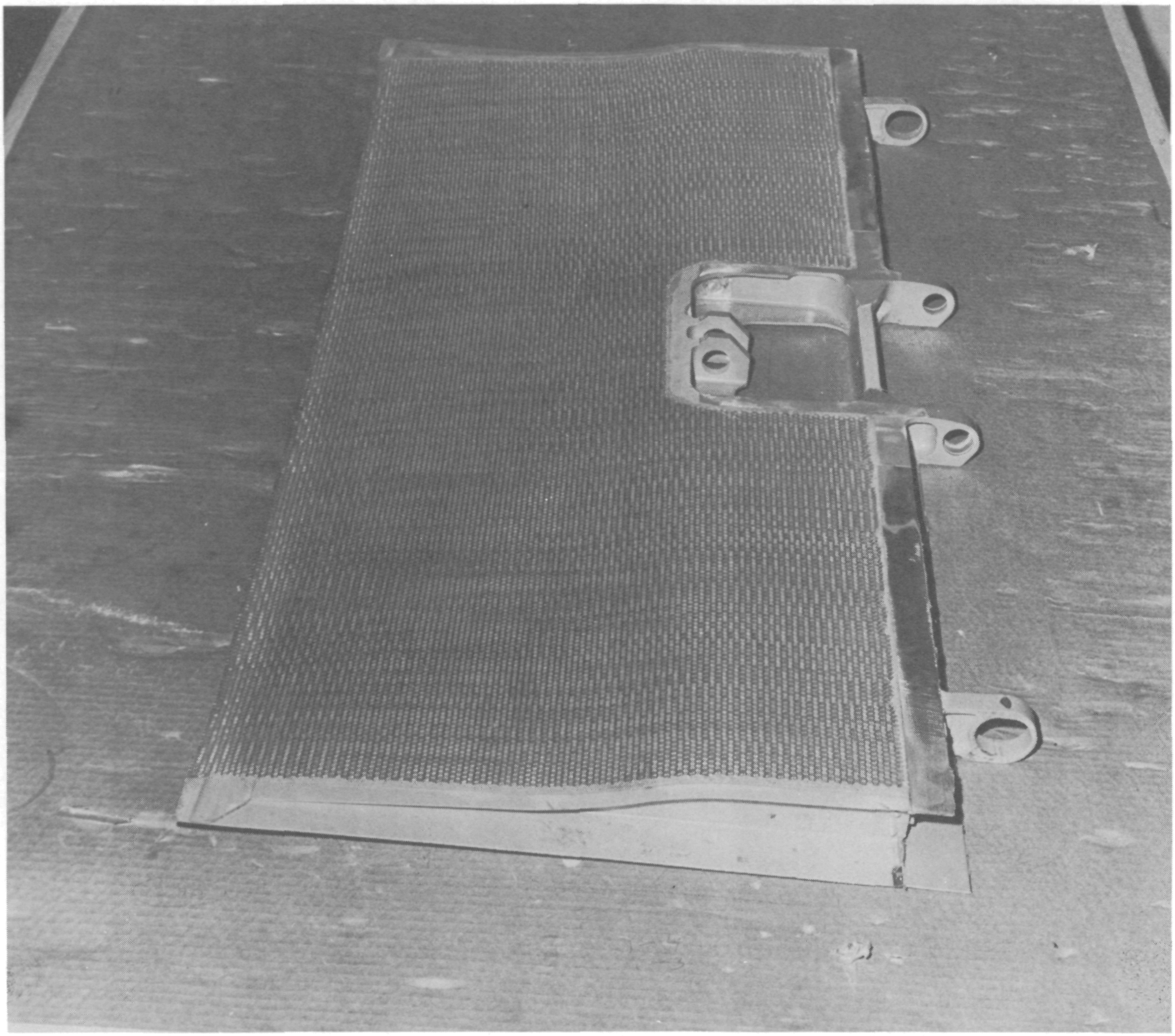


Figure 26.—Completed Spoiler Frame Assembly Ready for Bonding to Graphite Skins

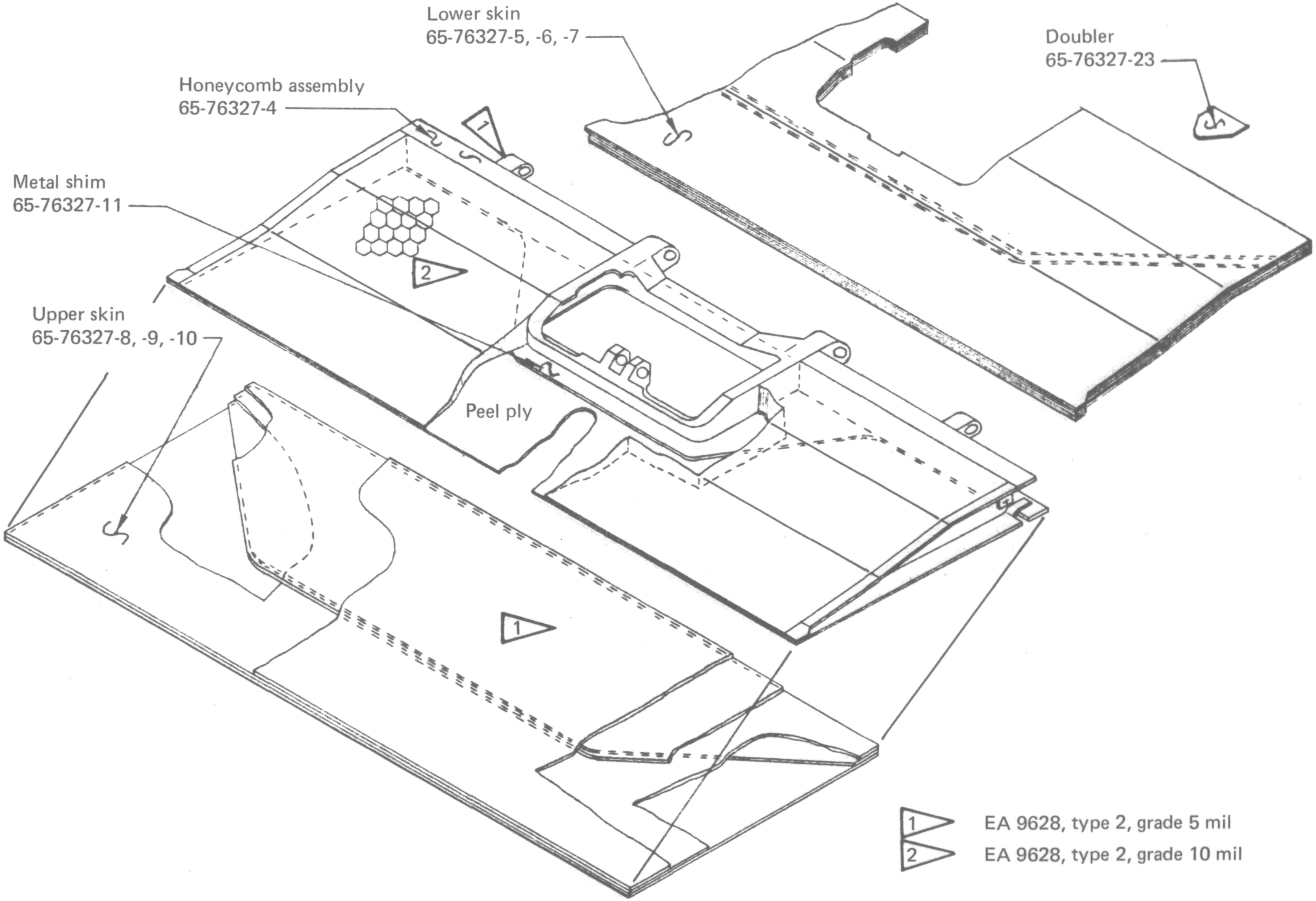


Figure 27.—Second-Stage Bond Assembly

- Clean and prepare XBAJ 65-76318-1.

  1. Apply MEK to the working face of the tool and wipe dry with clean cheesecloth.

  2. Apply separator film to base.

  3. Apply locating fixtures (fairing bars) on base plate for locating and holding details.

- Prepare detail and assemble.

  1. Remove EA 9628 grade 5- and 10-mil film adhesive from storage. Let warm at room temperature and apply to areas shown in figure 27.

  2. Cut the adhesive tape net size using the details as a pattern, but splice adhesive with no gap or overlap to a maximum of 13 mm (0.5 in.).

  3. Remove separator sheet from one side of tape and apply EA 9628 adhesive to entire peel ply surface of lower (contoured) and upper (flat) skin, as well as to -4 honeycomb assembly.

     a. Locate and load the upper skin onto tool base with adhesive surface up. Index to 3.2 mm (0.125 in.) diameter tool holes and pin in place.

     b. With care, locate and stack load the -4 assembly onto adhesive-applied skin.

     c. Secure end ribs and skin with 3.2 mm (0.125 in.) diameter tool pins. Install filler bars at flanges of end ribs to prevent crushing and tie down with fairing bars.

     d. Cut and remove adhesive in area of cutout in hinge fitting.

     e. Firmly press tape against faying surface and remove remaining separator sheet from adhesive.

     f. With care, locate and stack load the lower skin onto -4 honeycomb assembly.

     g. Ensure alignments at edges common to end ribs, leading-edge channels, and center hinge fitting cutout. Tie down skin as required with tape to hold alignment and prevent shifting.

     h. Ensure flat trailing edge.

  4. Remove separator sheet from one side of tape and apply 5-mil EA 9628 adhesive to -23 doublers in area common to lower skin.

a. Firmly press tape against faying surface and remove remaining separator sheet from adhesive.

b. Locate and load the -23 doublers onto lower skin. Tie down doublers as required with tape to hold alignment and prevent shifting.

5. Check to ensure that only light pressure (6900 to 13 800 Pa (1 to 2 psi) as calculated on the bond area) is required to give uniform contact over all surfaces to be bonded.

6. Install filler plug in cutout area of hinge fitting. Ensure end ribs are secured and filler bars are tightly fitted at flanges to prevent crushing.

- Prepare for cure (handle assembly and tool with care to prevent shifting).

  1. Apply FEP release film.

  2. Check to ensure flow of adhesive flash or gas is not restricted.

  3. Attach thermocouple wires.

  4. Apply bleeder cloth.

  5. Apply nylon bagging film.

  6. Draw vacuum, leak check, make necessary repairs, and release vacuum as soon as it is determined that the diaphragm is adequately sealed.

- Cure at 379 to 393 K (225^0 to 250^0 F); use 241 300 Pa (35 psi) for 90 minutes. Do not exceed 393 K (250^0 F).

- Debag.

- Remove bonding flash from periphery and notch in cutout common to center hinge fitting.

- Ultrasonic through-transmission inspect 100%.

THIRD-STAGE MECHANICAL ASSEMBLY

Assembly sequence for fillers, phenolic rub strip, bearings, and seals is given below.

- Bond fillers and phenolic strip to bond assembly.

  1. Clean bond faying surface with MEK.

  2. Apply thin coat of adhesive to each of the faying surfaces.

3. Apply sufficient pressure to ensure complete contact.

4. Cure at room temperature (297 to 300 K (75^0 to 80^0 F)).

- Locate and clamp drill jig (XDJ) onto upper (flat) surface of assembly and drill all holes full size.
- Remove XDJ from assembly; deburr and countersink holes.
- Inspect final operation.
- Install fasteners.
- Apply finish.

1. Apply static conditioner (pinhole filler) plus surfacer to all laminate surfaces.

2. Apply deSoto conductive coating base to all laminate surfaces. Ensure conductive coating is applied to the countersink surfaces.

   a. Cure.

   b. Measure resistance of the conductive coating.

3. Apply Boeing color 707 gray gloss enamel to composite and metallic surfaces.

- Install teflon bearings and bushings to center hinge fitting and lock bearings in place with -1100 retainer ring.
- Locate seals and install to assembly.
- Weigh assembly, inspect, and place in shipping container (fig. 28).

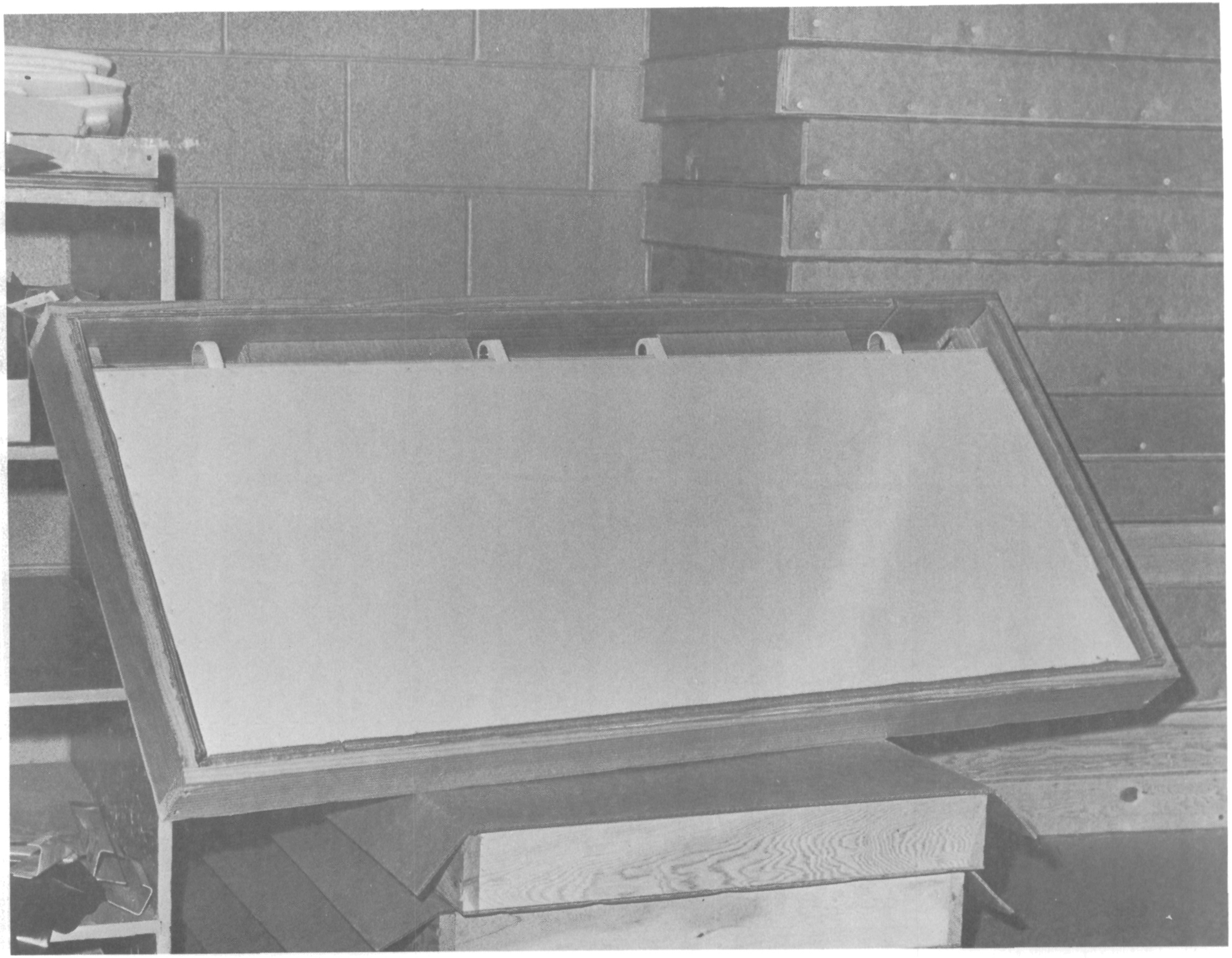


Figure 28.—Completed Spoiler in Shipping Container

QUALITY CONTROL

The major quality control effort was expended in the following areas.

- Nondestructive testing

    1. Numerous composite test specimens were evaluated nondestructively to aid in technique optimization. The technique and instruments used included water-column-coupled ultrasonic through-transmission, Sondicator, Fokker bond tester, and harmonic bond tester.

    2. Several reference standards were developed and evaluated to standardize instruments and to provide a common base for each inspection technique.

    3. The Boeing-developed C-scan multicolor recorder, which provides complete NDT information in a single scan, allows the recording of 10 discrete sound attenuation levels through the entire range of ultrasonic signals. Each attenuation level is represented by a different color. Progress was made toward improving the speed of the C-scan recording because it was relatively slow when compared to the conventional one-level, black and white recording.

    4. An improved multilevel standard was developed for greater accuracy in cross-panel comparison. This standard consists of a 10-step machined polyurethane plastic block that exactly attenuated the ultrasonic signal at the middle of each decibel level range.

    5. Inspection personnel were trained for production use of the NDT facility.

    6. A draft of the NDT procedure was prepared and was made available to Manufacturing prior to first-article inspection.

    7. Through-transmission ultrasonic NDT methods are not capable of distinguishing between voids and disbonds in a localized area of a highly dampening material such as thick adhesive. Other NDT methods such as low-voltage X-ray and Sondicator inspection were used for identification of thickened adhesives in local areas.

- Material control

    Incoming material was inspected and examined per Engineering requirements and reference 3.

- Process and facility control

    Process control was maintained during fabrication by conducting process surveillance checks to ensure that material, equipment, personnel, and processing steps were in compliance with the requirements of Boeing documents and the

contract. In conformity to established Boeing standards, all measuring instruments used in fabrication and inspection of spoilers were in full certification.

- Verifilm evaluation

  As an additional assurance of uniform pressure application throughout the bonding tool, several verifilm profiles were obtained on early production units. Verifilm is a specific term for the adhesive flow pattern obtained when the normal tape adhesive has been sandwiched between pieces of separator film and the spoiler is "bonded" per specification. The cured film is withdrawn from the bonded assembly for a critical examination of each bondline.

  The verifilm patterns of the first two panels indicated porosity and voids under the center hinge fitting to the -11 doubler bondline. These defects were not seen after the doubler was reworked to include vent holes. The verifilm also revealed low-pressure patterns on the lower skin-to-honeycomb bondline believed to be due to bent-over cell wall edges or excessively machined core. These same patterns were seen as high-attenuation areas on the ultrasonic C-scan.

PRODUCTION SPOILER INSPECTION

All composite production spoilers were nondestructively inspected using ultrasonic through-transmission with multilevel color C-scan recordings. Some of these recordings have shown areas of detectable ultrasonic signal attenuation. Details of these indications are shown in table 7, along with disposition report numbers contained in Engineering records. Most of the indications have occurred in the transition areas or under -11 shim. Some indications were seen under the -23 doublers and in a few cases adjacent to the -8 center hinge fitting. Additional adhesive was positioned around the -11 shim periphery, and the ultrasonic attenuation noted in that area was attributed to the thicker adhesive bondline.

EVALUATION OF NDT RESULTS

Ultrasonic through-transmission with multicolor C-scan recording was done by the production Quality Control personnel. All recordings were reviewed and evaluated by Quality Control Research and Development personnel, and disposition was made as needed. In some instances, parts were rescanned and/or examined by low-voltage X-ray or Sondicator. For example:

- The original scans of spoilers S/N 100 and S/N 103 lacked sufficient definition. The rescan of S/N 100 showed no discrepancies with the original NDT and S/N 100 was thus accepted. The rescan of S/N 103 duplicated 54- to 60-dB attenuation on the right hinge arm of the center hinge fitting that was noted on the original scan. Reexamination of the physical features of the hinge fitting disclosed that the attenuations were occurring over the 24.1 mm (0.95 in.) diameter machining access hole in the hinge fitting. While the open hole should theoretically show complete attenuation, apparently a portion of the signal was seeking a "detour" path around the periphery of the hole, yielding local indications greater than 0 dB. No such indications were noted adjacent to the access hole, and the spoiler was accepted.

Table 7.—NDT Test Data—Ultrasonic Inspection of Graphite-Epoxy Spoilers[a]

Panel		Serial number	Signal attenuation[b]	Satisfactory?	Disposition report number
Planning no.	Part no.				
65-76327-1	TE1	0001	43-48 dB under -23 doublers	No	
	TE2	0002	(c)	Yes	
	TE3	0003	43-54 dB transition area (L)	Yes	S/R 458141
	TE4	0004	43-54 dB -11 shim area (L and R)	Yes	S/R 930081
	TE5	0005	43-54 dB transition area;under -11 shim	Yes	S/R 458140
	TE6	0006	43-54 dB transition area; under -11 shim	Yes	S/R 458139
	TE7	0007	43-48 dB transition area (L); under -8 CHF	Yes	S/R 458138
	TE8	0008	43-48 dB transition area (L)	Yes	S/R 458137
	TE9	0009	43-48 dB -11 shim (center and L)	Yes	S/R 930083
	TE10	0010		Yes	
	TE11	0011		Yes	
	TE12	0012	43-48 dB over entire panel	Yes	S/R 930087
	TE13	0013	43-54 dB transition area (L); under -11 shim	Yes	S/R 930089
	TE14	0014	43-54 dB -11 shim; (L corner) inside surface -11 shim	Yes	S/R 930082
	TE15	0015	43-54 dB transition area (L); under -11 shim	Yes	S/R 930085
	TE16	0016	43-60 dB periphery -8 CHF; -11 shim	Yes	S/R 458136
	TE17	0017	43-48 dB under -11 shim	Yes	S/R 930084
	TE18	0018	37-42 dB under -11 shim	Yes	S/R 458135
	TE19	0019		Yes	
	TE20	0020		Yes	
	TE21	0021		Yes	
	TE22	0022	43-48 dB -11 shim (R)	Yes	S/R 458134
	TE23	0023	43-48 dB transition area (L and R); under -11 shim	Yes	S/R 458133
	TE24	0024		Yes	
	TE25	0025		Yes	
	TE26	0026	43-48 dB under -11 shim	Yes	S/R 458132
	TE27	0027	43-48 dB transition area (L and R); under -11 shim	Yes	S/R 458131
	TE28	0028	43-54 dB transition area (L and R); LE area (L); under -11 shim	Yes	S/R 458130
	TE29	0029	43-48 dB transition area (L); under -11 shim	Yes	S/R 458129
	TE30	0030	43-54 dB transition area (R); center of honeycomb; under -11 shim		S/R 458128
	TE31	0031		Yes	
	TE32	0032	43-54 dB transition area (L and R); under -11 shim; L side -8 CHF	Yes	S/R 458127
	TE33	0033	43-54 dB transition area; under -11 shim and upper R side	Yes	S/R 640070
	TE34	0034	43-60 dB center honeycomb to trailing edge in distinct, irregular areas	No	R/T 495030 Retested and rejected
	TE35	0035	43-54 dB transition area (L); under -11 shim	Yes	S/R 640069
	TE36	0036	43-54 dB transition area (L); under -11 shim; stripe 5 in. R of CHF	Yes	S/R 640068
	TE37	0037	43-60 dB upper R corner; two indications near trailing edge	No	R/T 465503 Rejected and repaired
			Repaired part: 43-60 dB upper right corner	Yes	S/R 640071
	TE38	0038		Yes	
	TE1R	0001R		Yes	
65-76327-1	TE34R	0034R		Yes	
65-76327-2	TE1	0041	(c)	Yes	
65-76327-2	TE2	0042	43-54 dB inside -8 CHF	Yes	S/R 930080
65-76327-2	TE3	0043	43-54 dB L side of panel	Yes	S/R 930086

Table 7.—Continued

Panel		Serial	Signal attenuation	Satisfactory?	Disposition
Planning no.	Part no.	number			report number
65-76327-2	TE4	0044		Yes	
↑	TE5	0045		Yes	
	TE6	0046	43-54 dB transition area (R)	Yes	S/R 930090
	TE7	0047	43-54 dB under -23 doublers, -11 shim; and transition area (L)	Yes	S/R 458126
	TE8	0048	43-60 dB -8 CHF (L); under -11 shim and -23 doublers	Yes	S/R 930092
	TE9	0049		Yes	
	TE10	0050	43-60 dB transition area (L and R); under -11 shim and -23 doublers	Yes	S/R 930091
	TE11	0051		Yes	
	TE12	0052	43-54 dB transition area (L and R); under -11 shim	Yes	S/R 507070
	TE13	0053		Yes	
	TE14	0054		Yes	
	TE15	0055		Yes	
	TE16	0056		Yes	
	TE17	0057	43-48 dB transition area (L and R); under -11 shim and -23 doublers	Yes	S/R 507069
	TE18	0058	43-48 dB transition area (L and R); under -11 shim	Yes	S/R 507068
	TE19	0059		Yes	
	TE20	0060		Yes	
	TE21	0061	43-48 dB transition area (L and R); under -11 shim	Yes	S/R 507067
	TE22	0062	43-54 dB transition area (L and R); under -11 shim	Yes	S/R 507066
	TE23	0063	43-54 dB transition area (L and R); under -11 shim	Yes	S/R 507065
	TE24	0064	43-54 dB transition area (L and R); under -11 shim	Yes	S/R 507064
	TE25	0065	43-48 dB transition area; under -11 shim and upper R	Yes	S/R 507054
	TE26	0066	43-54 dB transition area (L and R); under -11 shim and -23 doublers	Yes	S/R 457453
	TE27	0067	43-54 dB transition area; under -11 shim	Yes	S/R 507062
	TE28	0068	43-54 dB transition area (L, center, R); under -11 shim	Yes	S/R 507063
	TE29	0069	43-60 dB, most of upper (LE) side of panel	Yes	S/R 457454
	TE30	0070	43-48 dB transition area (L and R); under -11 shim	Yes	S/R 457455
	TE31	0071	43-48 dB transition area (L and R); under -11 shim	Yes	S/R 507061
	TE32	0072	43-54 dB scattered over panel	Yes	S/R 457451
	TE33	0073	43-54 dB transition areas (L and R); under -23 doublers; stripe 6 in. L of -8 CHF; stripe 5 in. R of CHF	Yes(d)	S/R 457450
	TE34	0074	43-54 dB transition area (L and R); under -11 shim and -23 doublers	Yes	S/R 457449
	TE35	0075	43-54 dB transition area (L and R); under -11 shim and -23 doublers; stripe 5 in. R of CHF	Yes	S/R 457448
	TE36	0076	43-54 dB transition area (L and R); under -11 shim and -23 doublers; stripe 5 in. R of CHF	Yes	S/R 457447
↓	TE37	0077	43-48 dB transition area; under -11 shim and -23 doublers	Yes(d)	S/R 457446
65-76327-2	TE38	0078	43-54 dB transition area (R) and under -11 shim; stripe 6 in. R of CHF	Yes	S/R 457452

Table 7.—Concluded

Panel		Serial number	Signal attenuation[b]	Satisfactory?	Disposition report number
Planning no.	Part no.				
65-76327-3	TE1	0081		Yes	
	TE2	0082		Yes	
	TE3	0083		Yes	
	TE4	0084	43-60 dB over -11 shim	Yes	S/R 930088
	TE5	0085		Yes	
	TE6	0086		Yes	
	TE7	0087		Yes	
	TE8	0088	43-48 dB transition area (L, center, R); under -11 shim	Yes	S/R 507059
	TE9	0089	43-45 dB transition area (L and R); under -11 shim	Yes	S/R 507055
	TE10	0090	43-48 dB transition area; under -11 shim	Yes	S/R 507058
	TE11	0091	43-54 dB transition area (L and R); under -8 CHF and -11 shim	Yes	S/R 507057
	TE12	0092	43-54 dB transition area (L and R); under -11 shim	Yes	S/R 507056
	TE13	0093	43-54 dB under -11 shim; stripe 7 in. R of CHF	Yes	S/R 640066
	TE14	0094	43-54 dB under -11 shim and -23 doublers	Yes	S/R 640065
	TE15	0095	43-60 dB entire panel between LE and transition area; 43-48 dB over remainder of panel	Yes[c]	S/R 640064
	TE16	0096	43-54 dB stripe 6 in. R of CHF	Yes	S/R 640063
	TE17	0097	43-54 dB upper LE panel area from 5 in. R of -8 CHF to L end rib	Yes	S/R 640062
	TE18	0098	43-54 dB under -11 shim	Yes	S/R 640061
	TE19	0099	43-54 dB transition area (L) and under -23 doublers and -11 shim; stripe 4 in. L of CHF	Yes	S/R 640060
	TE20	0100	43-54 dB entire spoiler area	Yes[c]	S/R 640059
	TE21	0101	43-54 dB entire upper LE panel area	Yes	S/R 640058
	TE22	0102	43-54 dB transition area (L and R), stripes 5 in. L and R of CHF	Yes	S/R 640057
	TE23	0103	43-48 dB over entire spoiler area	Yes[c]	S/R 640056
	TE24	0104	43-54 dB under -11 shim	Yes	S/R 640055
	TE25	0105	No initial NDT performed. Scan after service damage, 1-in.-dia void on upper surface above CHF	Yes[d]	R/T 494681
	TE26	0106	43-54 dB stripe 4 in. of -8 CHF	Yes	S/R 640077
	TE27	0107	43-60 dB under -11 shim; spotty upper panel area	Yes	S/R 640078
	TE28	0108	49-54 dB under -11 shim; upper panel area	Yes	S/R 640079
	TE29	0109	43-54 dB transition area (R); under -23 doublers; -11 shim periphery; stripe 4 in. L of -8 CHF	Yes	S/R 457467
	TE30	0110	43-54 dB transition area (L, center, R); under -11 shim	Yes	S/R 457466
	TE31	0111	43-54 dB all transition area; periphery -11 shim; stripe 5 in. R of -8 CHF	Yes	S/R 457463
	TE32	0112	43-54 dB under -11 shim and stripe 4 in. L of CHF	Yes	S/R 457462
	TE33	0113	43-54 dB under -11 shim and stripe 4 in. L of CHF; 49-54 dB in 1/2-in. dia 8 in. L of CHF and 9 in. forward of TE	Yes	S/R 457461
	TE34	0114	43-48 dB periphery and R side -11 shim; R -23 doubler	Yes	S/R 457460
	TE35	0115	43-54 dB under -11 shim and 4 in. L of CHF	Yes	S/R 457459
	TE36	0116	43-48 dB transition area (L and R); under -11 shim	Yes	S/R 457458
	TE37	0117	43-54 dB transition area (all); under -11 shim	Yes	S/R 457457
65-76327-3	TE38	0118	43-54 dB transition area (L and R); under -11 shim	Yes	S/R 457456

[a]1-MHz water-column-coupled through-transmission ultrasonic signal

[b]Abbreviations used: L (left), R (right), CHF (center hinge fitting), LE (leading edge), and TE (trailing edge)

[c]Rescan cleared discrepant areas

[d]Repaired-area only

- Unit S/N 0093, with high attenuation in the leading-edge region, was radiographically inspected using a 50-kV source. A high level of adhesive bondline porosity was displayed over the entire panel area. The X-ray film image also displayed some core crushing and distortion, which could account for the high attenuation readings.

- The investigation of scrapped spoiler S/N 0034 was not made because the unit was salvaged for detail parts before the structural bondline information could be obtained. The rebuilt spoiler S/N 0034R contained no discrepant areas.

STATIC TEST SPOILER EVALUATION

Three static test spoilers–S/N 0002, S/N 0041, and S/N 0081–were rescanned after static testing. The highly attenuated areas were generally confined to the fracture areas, with little or no propagation into adjacent structure. Radiographic inspection of these areas also confirmed negligible crack propagation. It was interesting to note the small edge crush on the honeycomb core in the transition areas, which also might account for sonic attenuation indications. The first two static test spoilers (S/N 0002 and 0041) were run using a black and white recording since the static test articles would not require future reference to color recordings. However, color recordings were made on unit S/N 0081.

Unit S/N 0002 was destructively evaluated by Quality Control personnel following the static test. Attempts to mechanically remove the upper and lower skins from the honeycomb core resulted in complete destruction of the core. The skin laminates invariably would delaminate before failure of either the honeycomb-to-laminate bondline or the laminate-to-edge-member bondline. Adhesive bonding was termed excellent.

To interpret the significance of the relationship between ultrasonic transmission through the panel to that through actual structure, S/N 0081 was evaluated by radiography and destructively tested by chemical milling the core away from the skins. The results of this investigation strengthened the belief in ultrasonic recording interpretations.

NDT INSPECTION PROCEDURE

All spoilers produced under this contract were inspected over their entirety using water-column-coupled through-transmission equipment augmented with 0- to 60-dB, 10-level multicolor recording capability for approximately 1:1 C-scan presentation (fig. 29).

EQUIPMENT

The source was a Sperry-Rand model 724 immerscope, a high-voltage pulse generator that periodically excites a transmitting transducer to emit an acoustic signal (1 MHz) of fixed amplitude and duration.

The sound coupling medium was city tap water columns of fixed pressure and flow. One water column proceeded from the source transducer housing to the test hardware, the

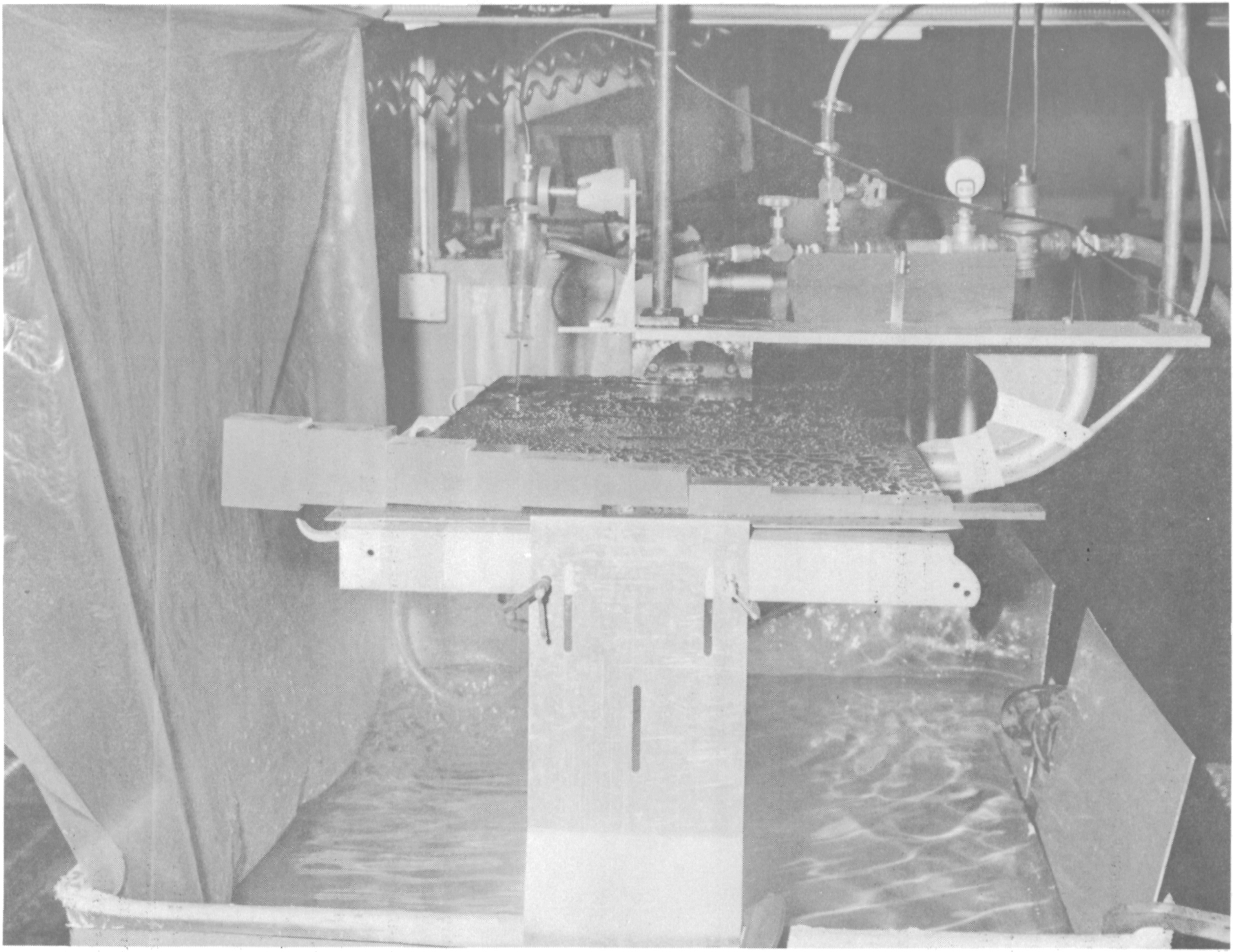


Figure 29.—General Arrangement—Ultrasonic Inspection Setup

other from the receiver transducer housing to the opposite side of the test hardware (fig. 30). Pressure and flow were such as to eliminate all entrapped gases within the water column. The water columns were aligned prior to test for maximum signal level.

The receiver was electronically arranged for conversion of the transmitted sonic pulse into the required electrical signal. The output of the receiver transducer was amplified and processed in a peak detector. The dc signal developed in the peak detector was connected through logic circuitry for definition of 10 attenuation levels, each 6 dB in width (0- to 60-dB total range). Each activated level actuated an indicator lamp and a relay/solenoid circuit for depressing the appropriate colored pen.

The conditioned dc signal was either displayed on a cathode-ray tube of a dual-trace oscilloscope or was used to activate the colored pen circuits (fig. 31). The color code used for the attenuation levels is as follows.

Attenuation level, dB	Colored pen activated
0-6	Pink
7-12	Turquoise
13-18	Gold
19-24	Blue
25-30	Green
31-36	Purple
37-42	Orange
43-48	Red
49-54	Brown
55-60	Black

Indications above 43 dB are considered to be highly attenuated.

A suitable scanning table or gantry with control equipment was used to effect 1.02 to 2.04 mm (0.040 to 0.080 in.) steps, each 711 mm (28.0 in.) long, for moving the water-coupled ultrasonic transmitter/receiver yoke across the entire surface of the spoiler unit. The selsyn controller shown in figure 31 correlated movement of the pen carriage to movement of the yoke assembly across the panel.

STANDARDS

A 30-ply micarta block used during the start of the program was replaced by a 10-step polyurethane block (figs. 29 and 30) to standardize the equipment. Each step or thickness variation was constructed to attenuate at midrange of each decibel interval. A Tektronix model 170 calibrated signal attenuator (fig. 32) was used in conjunction with the test block.

PROCEDURE

1. Turn on immerscope, log amplifier quantizer, and oscilloscope at least 2 hours prior to test.

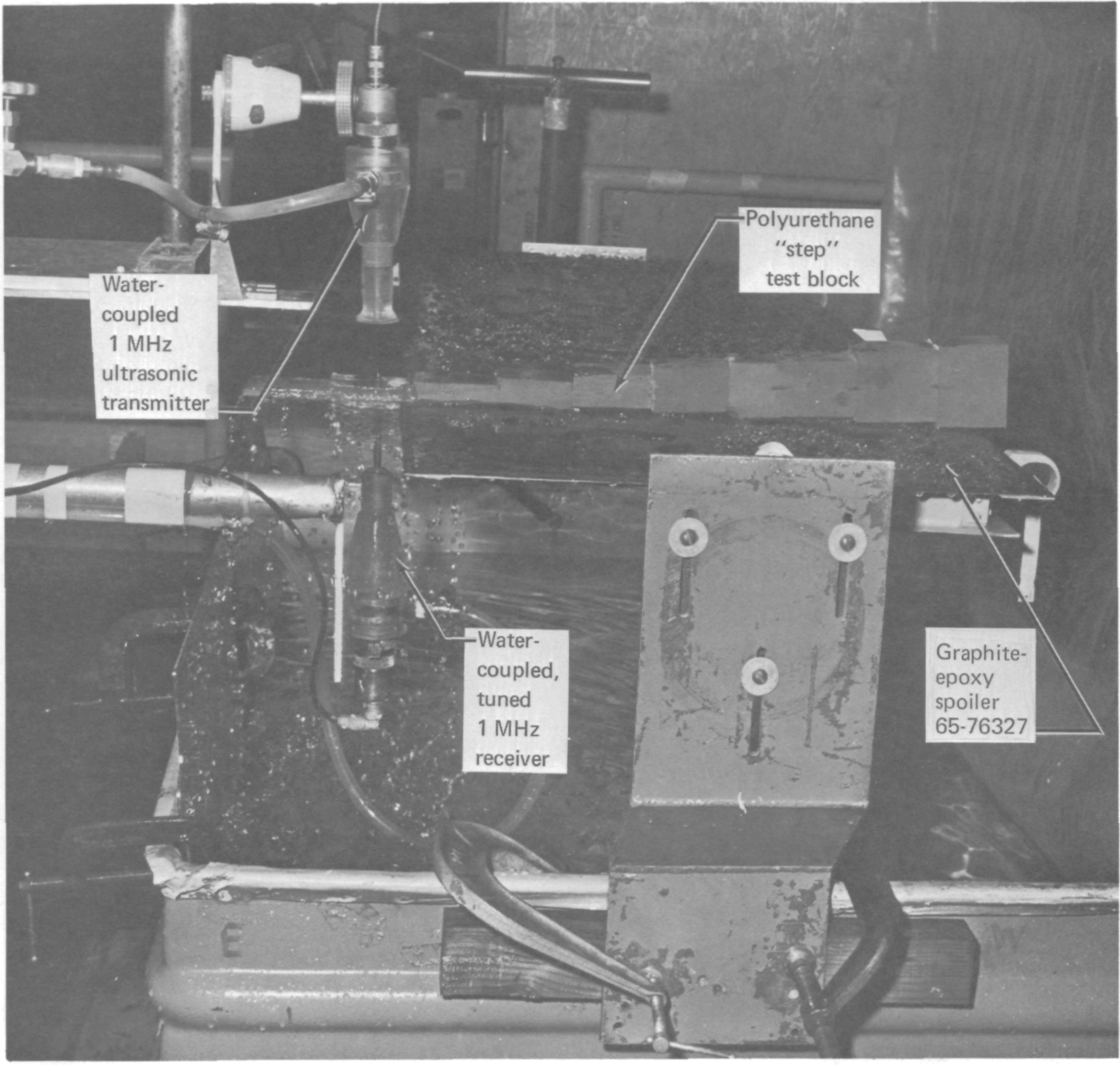


Figure 30.—Ultrasonic Signal Transmitter and Receiver Arrangement

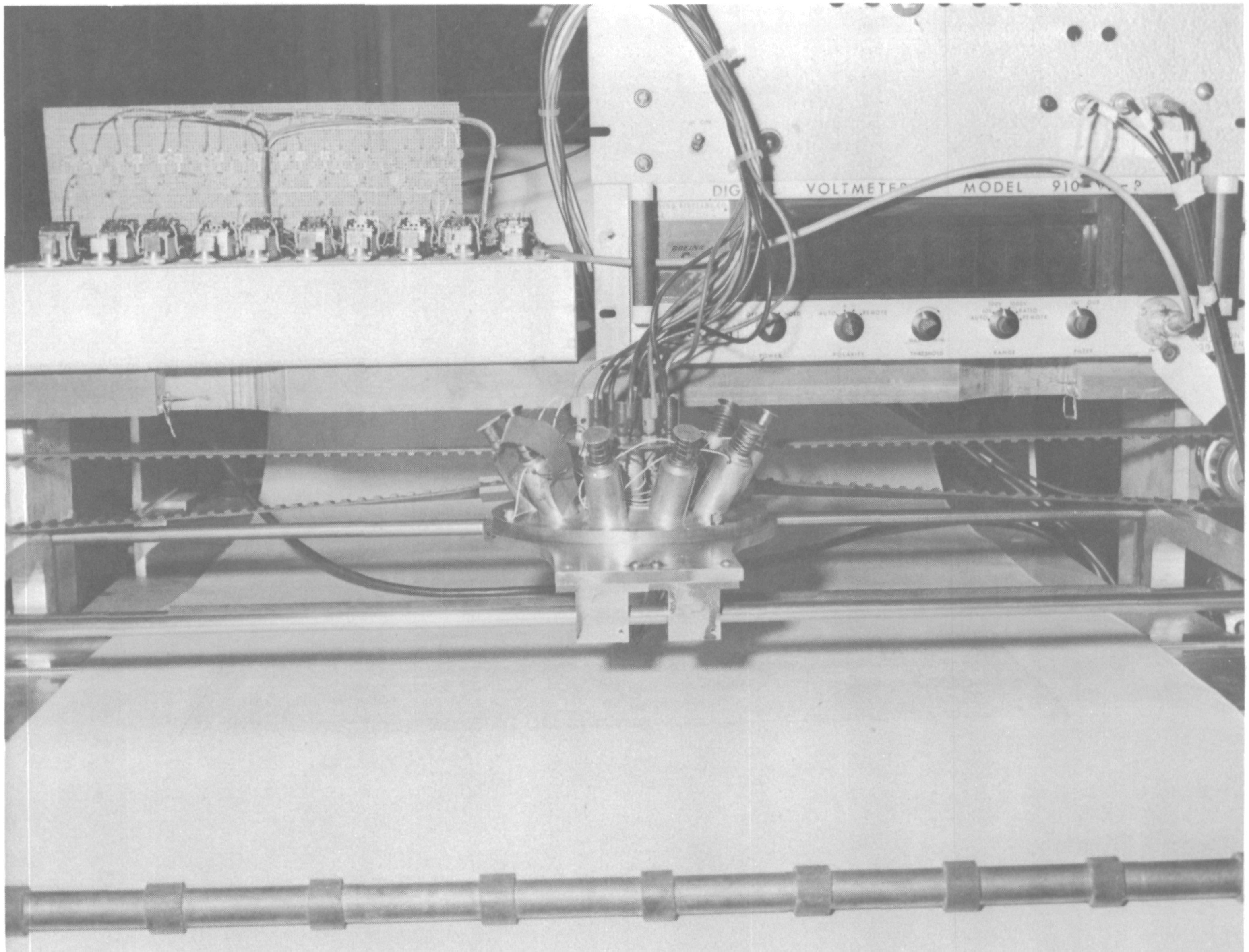


Figure 31.—10-Level Quantizer and 10-Colored-Pen Array

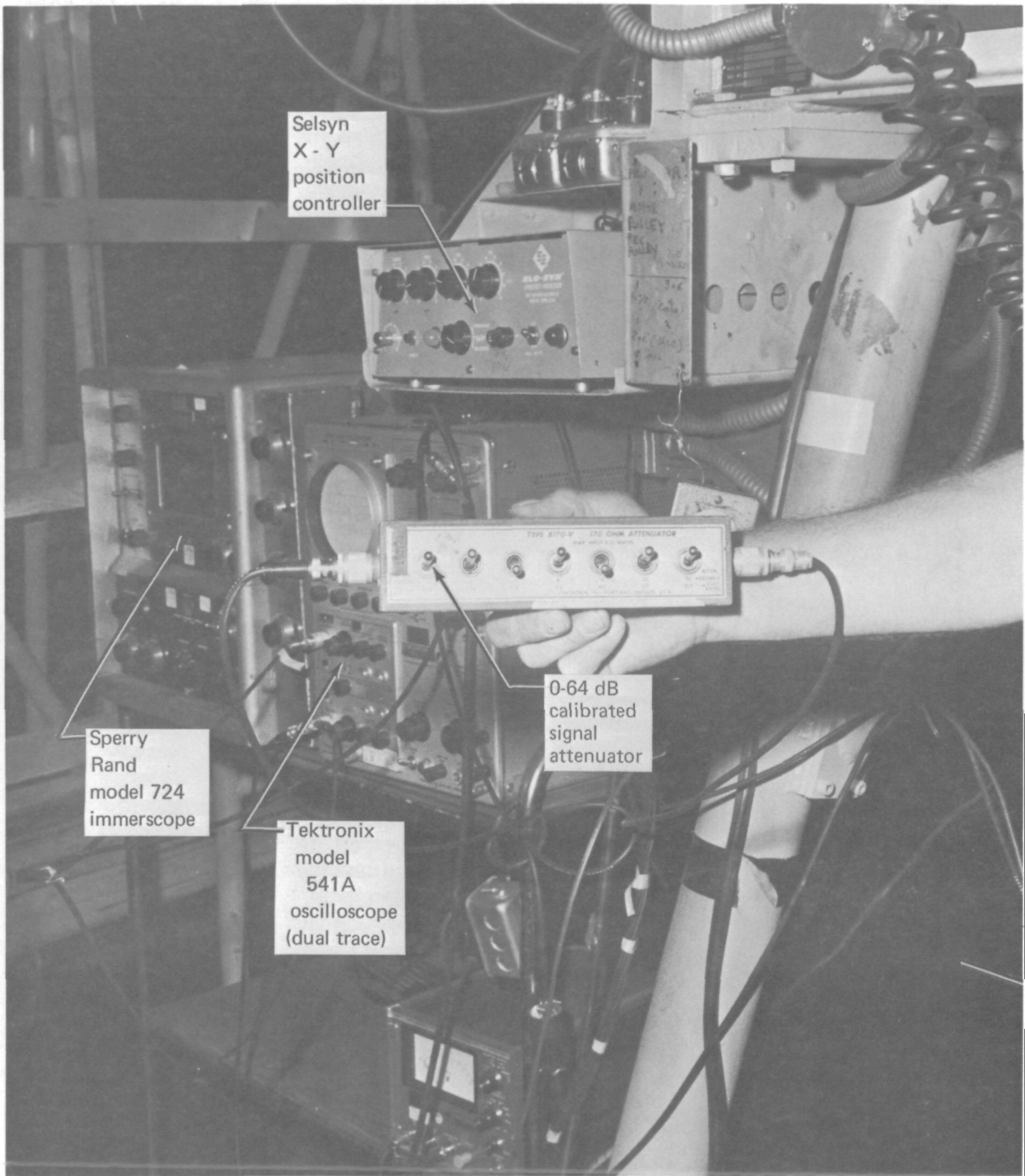


Figure 32.—Calibrated Signal Attenuator and Ultrasonic Equipment Controls

2. Preset the water pressure to 137 900 to 172 400 Pa (20 to 25 psi). Align the water jets so that the splash pattern is perpendicular to the water flow and approximately midway between the transducers. Check for air bubbles in the line and eliminate if present. The electrical signal on the DVM should be a steady 13.4 Vdc once peak voltage is obtained. Note: The slightest misalignment of the transducers will strongly reduce the signal received.

3. Preset the scanner stops to cover 711 mm (28 in.) of travel across the width of the test hardware. Set selsyn pen drive for 1.02-mm (0.04-in.) or 2.04-mm (0.08-in.) steps as required for 1:1 data display of the C-scan.

4. Place the model 170 attenuator in series with the output from the receiver transducer to the log-amp detector.

5. Place the 10-step polyurethane test block in the water path, observing the signal level actuated for each step of the block (i.e., colored lights and pen solenoid actuation). If the actuated signal level varies from standard (i.e., the seventh block actuates a red pen instead of an orange one), adjust the attenuator until the proper signal level is attained. Rescan the other sections of the test block to verify that proper attenuation has been maintained. Reverify the unimpeded signal at 13.4 Vdc and ensure constant signal level when the scanner is put into motion.

6. Turn on chart drive control.

7. Place the test block in its holder and scan across each section three or four times. The colored pen presentation should be uniform for each color and should change to the next highest attenuation level cleanly. Remove the test block. Retain this display on the same chart as the spoiler scan.

8. Place the graphite spoiler in the support clamp with the upper skin upward and at right angles to the source transducer. Move the transducer/water column yoke to either end of the spoiler. Set the edge stops (leading and trailing edges) so the yoke extends 13 to 26 mm (0.5 to 1 in.) beyond each edge.

9. Start selsyn drive and stepping motor control to start scan. Scanning time is normally 2 to 3 hours.

10. As yoke moves lengthwise across spoiler, index the C-scan at each 152-mm (6-in.) mark of the spoiler.

11. Observe and correct sticking pen solenoids whenever they occur during a scan. Lubricate with MEK and graphite powder.

12. After the scan, remove the graphite spoiler and wipe dry with absorbent toweling.

13. Observe color pattern on C-scan for highly attenuated areas. Recalibrate and rescan as necessary to verify attenuation levels.

14. Store C-scan with the production planning paper for later study.

As an additional assurance that the adhesive-bonding techniques and materials being employed on the spoiler program were yielding complete and fully filleted bonding of the honeycomb core to the composite skin panels, a portion of a spoiler was selected for destructive evaluation. A 457-mm (18-in.) section was cut from the end of the 65-76327-3 static test spoiler (S/N 0081) and designated by Quality Assurance as representative of the fabrication techniques being employed. The specimen was further divided with spanwise cuts into three equal sections for ease of handling and evaluation (fig. 33). These three sections were then immersed in a chemical-milling solution to chemically remove all the aluminum material, leaving the cured adhesive, graphite composite, and fiberglass materials intact.

Each section of the chemically treated specimen was visually assessed by Quality Assurance personnel. Filleting of the honeycomb core was termed as 100%, with generous flow of adhesive along the nodes. Figures 34 through 37 show the filleting achieved on the interior surfaces of the skins.

MANUFACTURING COSTS

One of the most significant factors that continues to impede the general usage of carbon composites in aircraft structural applications is the uncertainty regarding fabrication costs. The availability of cost data covering fabrication of significant quantities of structural components is extremely limited. Since the graphite-epoxy flight spoiler program offers an exceptional opportunity to monitor fabrication costs in a production-shop environment, the data derived from this program should be considered to be of substantial importance.

The cost collection system was set up to receive charge inputs from the several production shops involved in the fabrication effort. All labor charges from the participating shops were accumulated against a single work order number. These charges were cumulative against the shop activity for this effort and were not associated with the effort expended on any one unit, with the exception of the composite skins that were made in lots of four and were identifiable in the cost collection system as separate production lots. Figures 38 and 39 show the variation in man-hours for fabrication of skin laminates and bonded spoiler assemblies, respectively.

In addition to the direct labor charges associated with spoiler fabrication, additional nonrecurring activities assessable to the spoilers were identified. Those activities and hours, which represent a sizable (one-third) increment of the total expenditures on this program, are shown in table 8.

Table 9 shows a breakdown of direct labor and material costs for an average graphite composite spoiler fabricated in this program. The total direct labor hours are further identified in table 10. A breakdown of the graphite composite material utilization has been prepared and is shown in table 11.

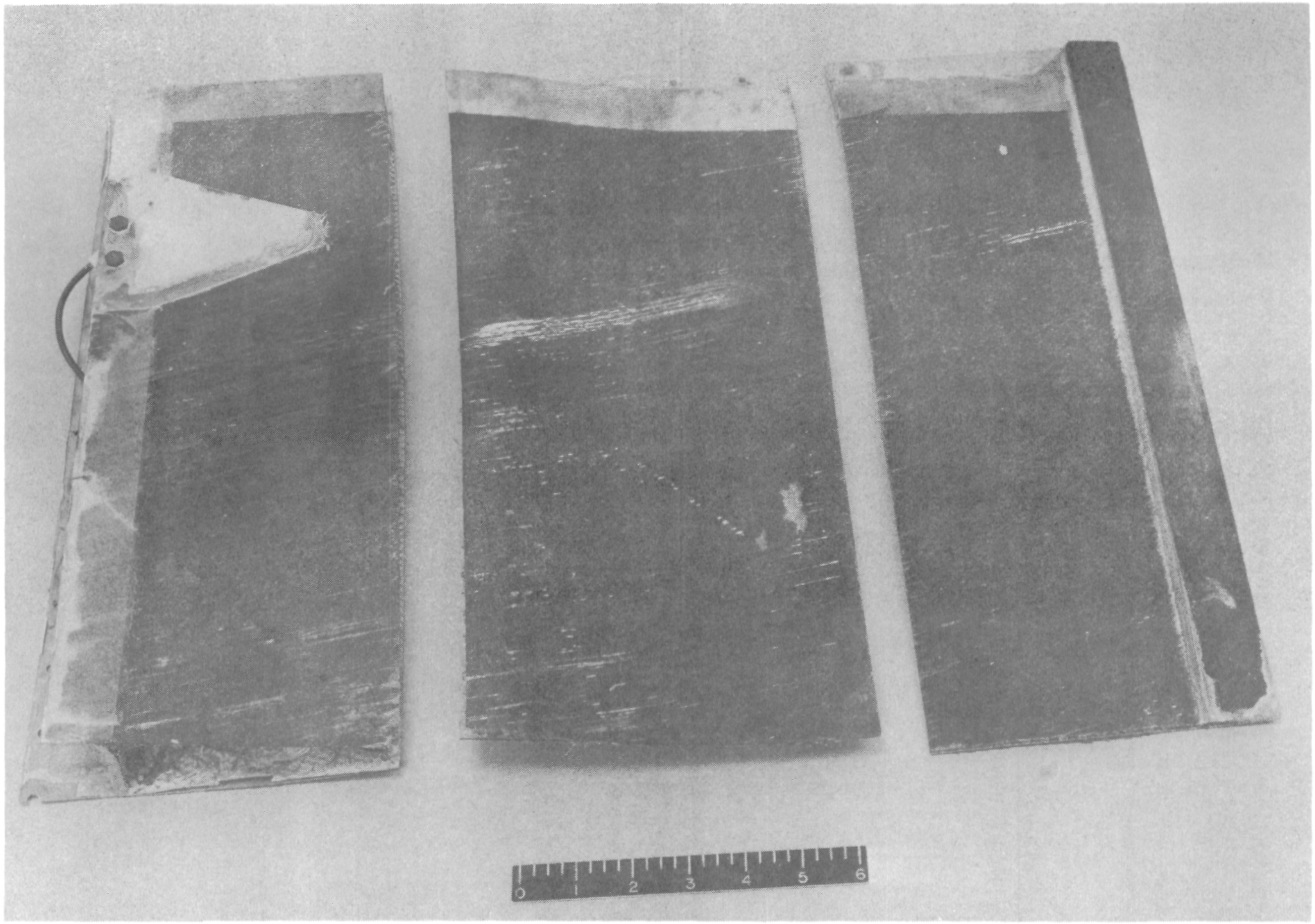


Figure 33.—Chem-Milled Sections of -3 Test Spoiler

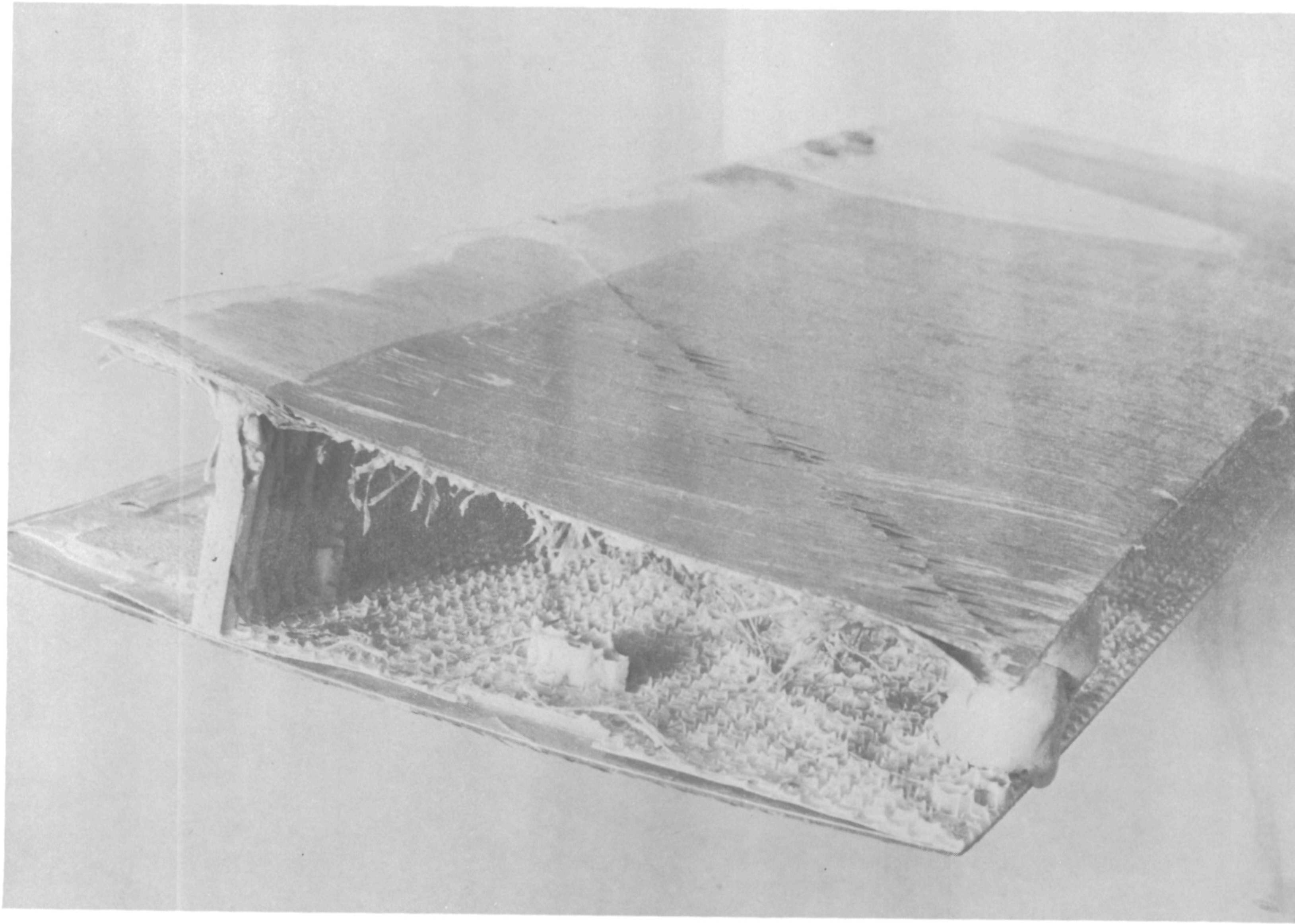


Figure 34.—Adhesive Filleting Near Leading Edge

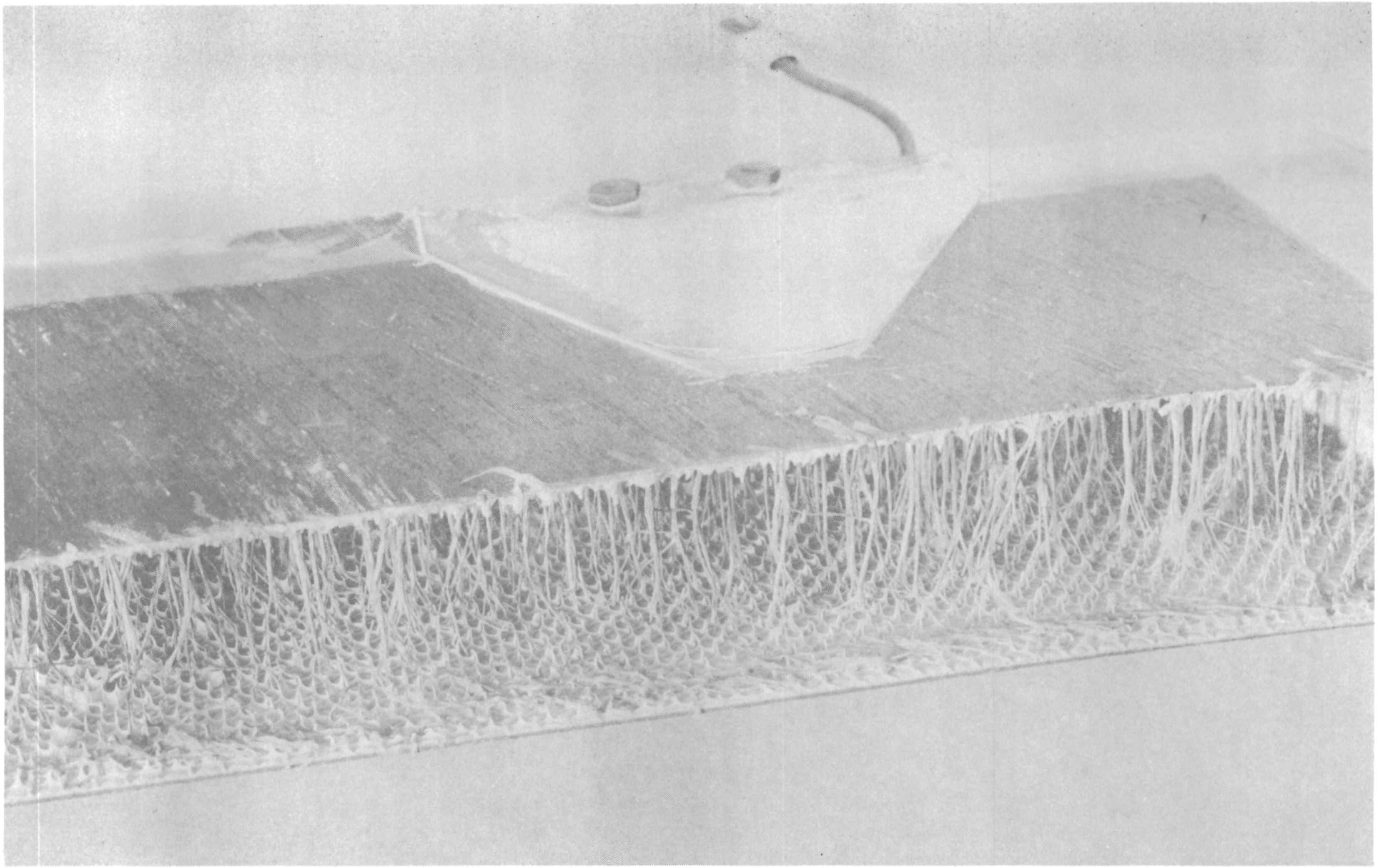


Figure 35.—Adhesive Filleting and Core Node Bonding

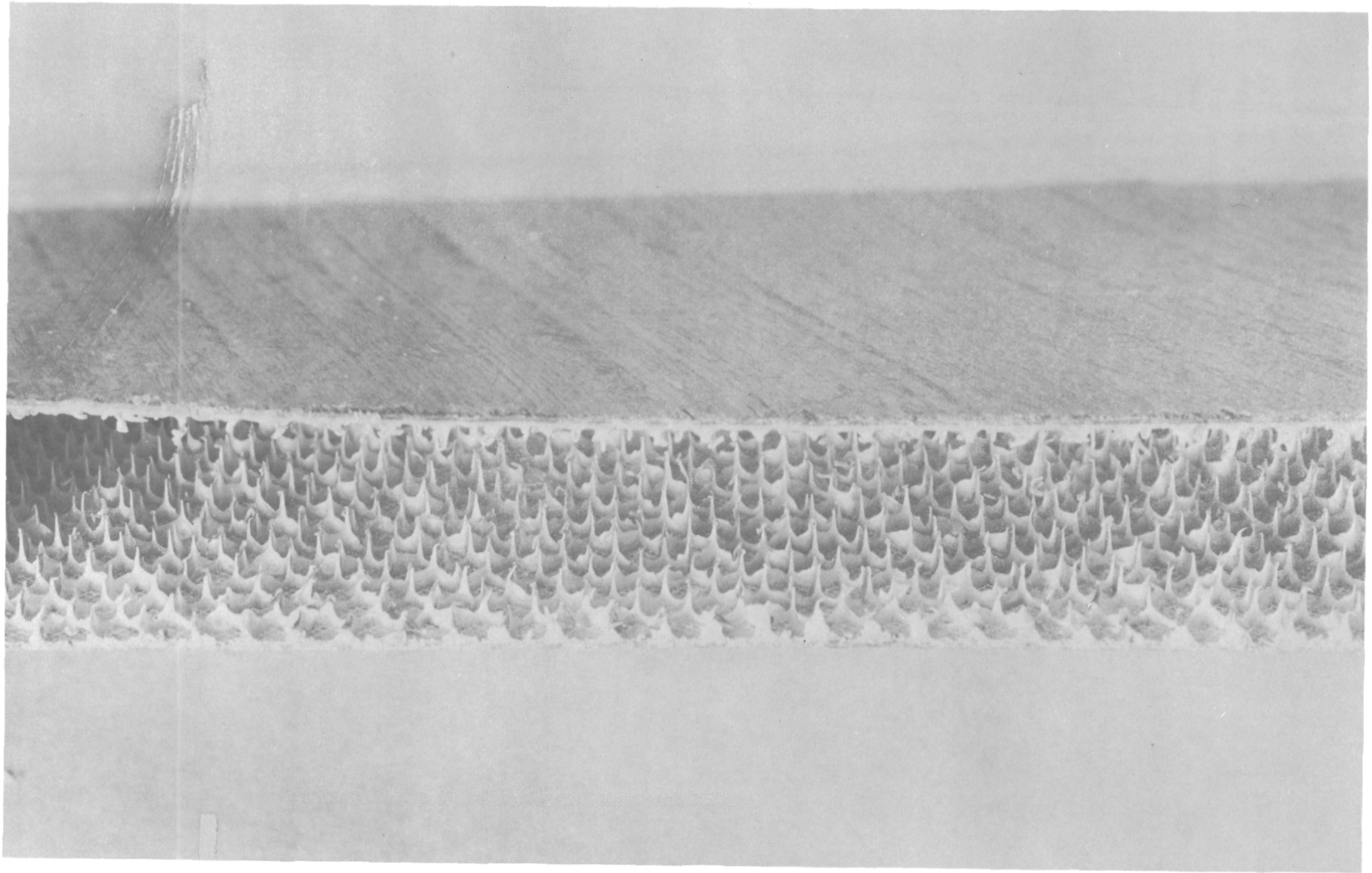


Figure 36.—Closeup of Skin-To-Core Adhesive Filleting

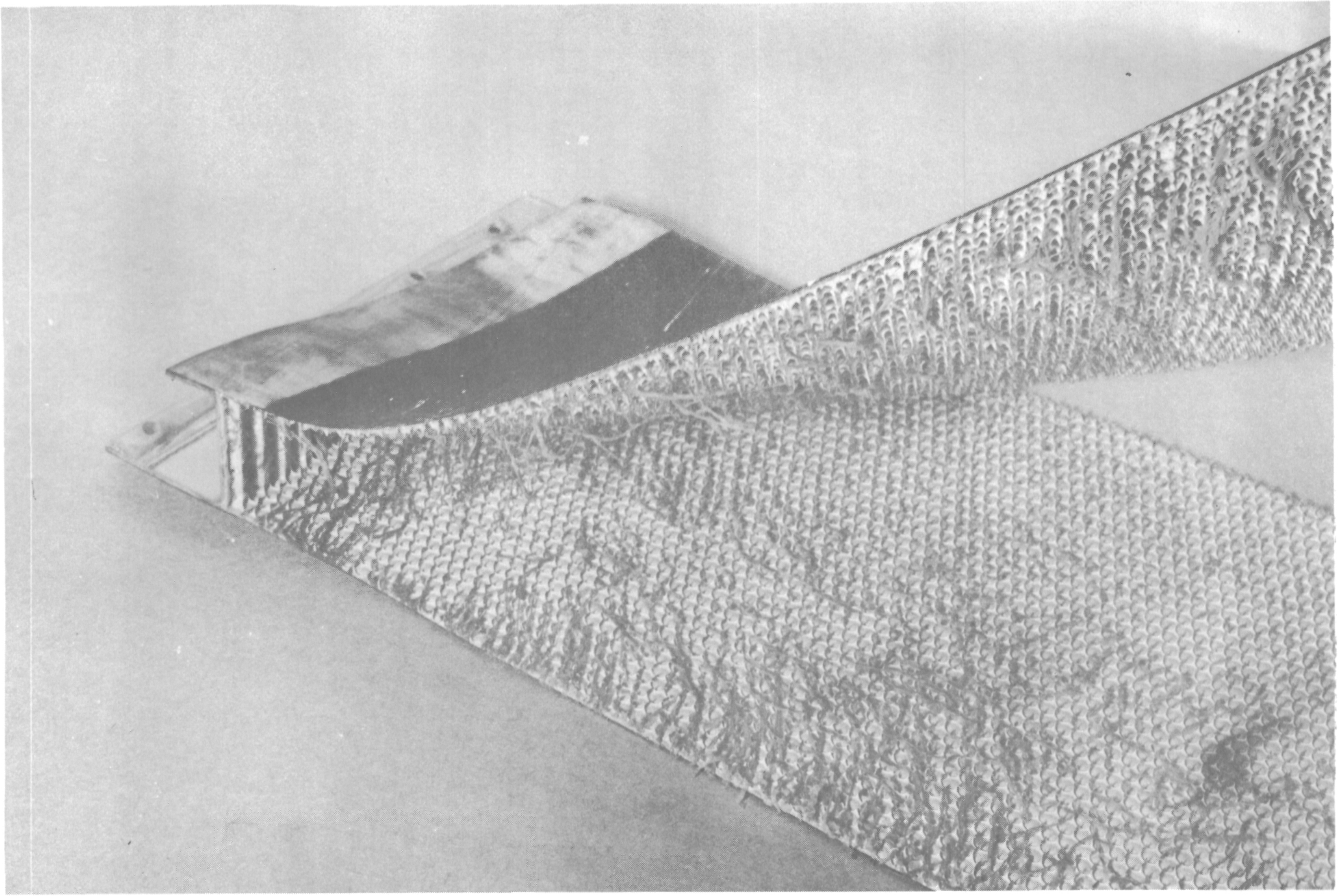


Figure 37.—Adhesive Filleting and Core Node Bonds, Transition Section

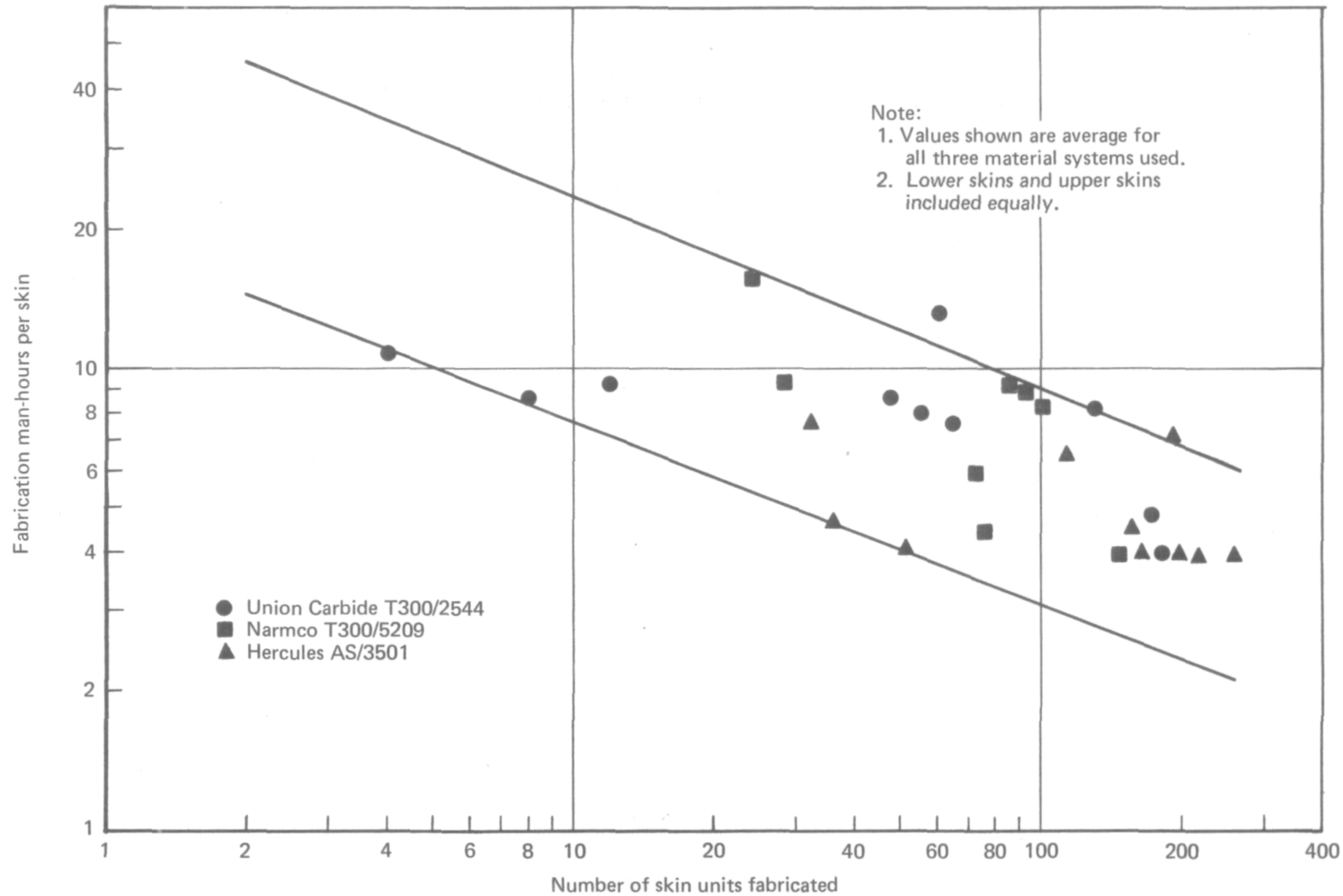


Figure 38.—Man-Hours Required for Skin Laminate Fabrication

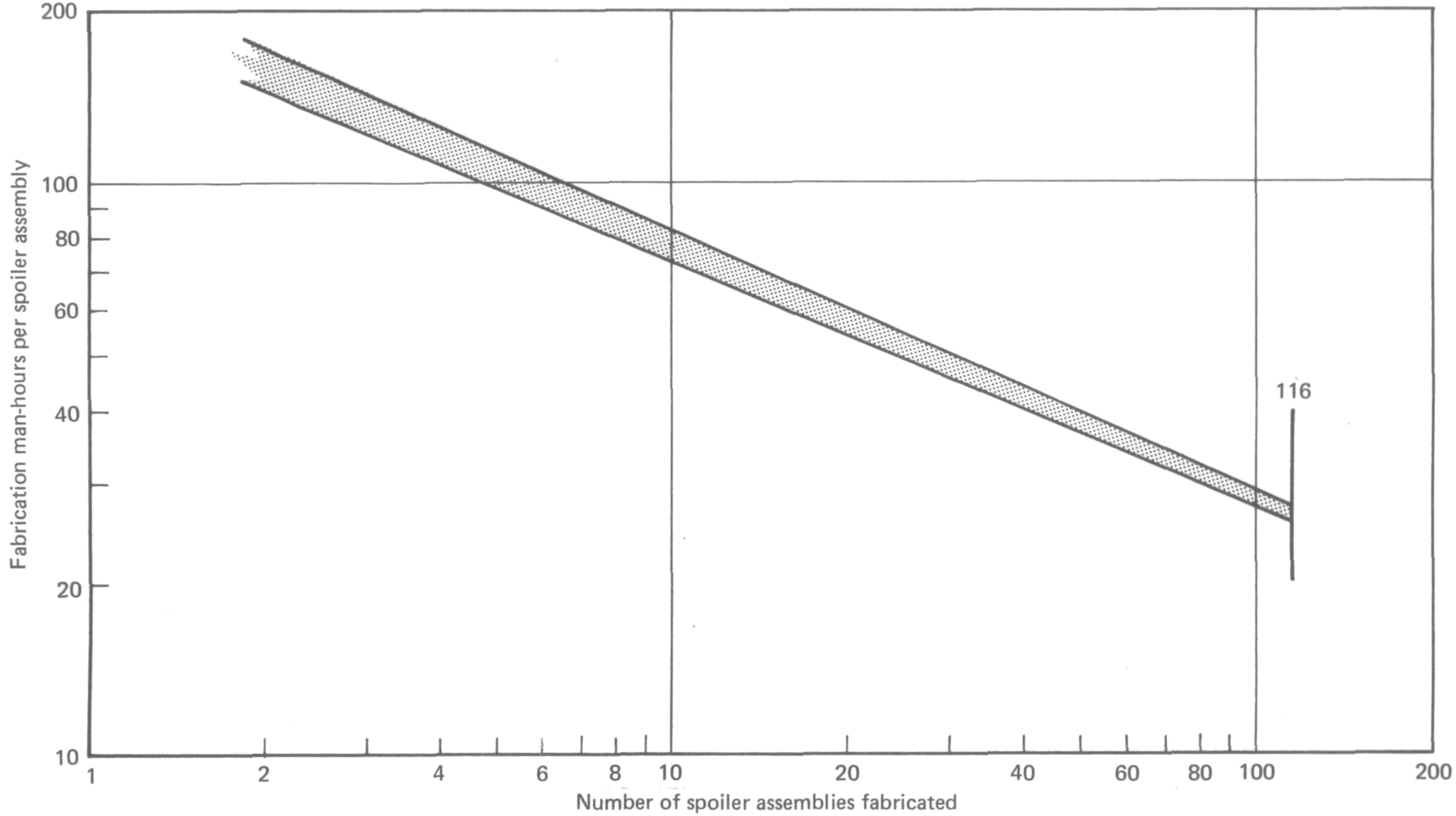


Figure 39.—Man-Hours Required for Spoiler Assembly

Table 8.—Nonrecurring Labor Expenditures

Function	Labor Hours	Labor Percent
Tooling fabrication	2358	25.7
Manufacturing engineering	525	5.7
Tool grinding (modification)	54	0.6
Materiel	122	1.3
Subtotal	3059	
Recurring labor hours (114 total spoilers)	6116	66.7
Total	9175	100.0

Table 9.—Average Composite Spoiler Fabrication Costs

Component	Material costs	Labor Hours	Labor Percent
Purchased Parts			
Center hinge fitting	$255.00		
Outboard slotted hinge (2)	45.50		
Leading-edge channel (2)	37.00		
Seals	10.00		
Fasteners	1.50		
Honeycomb core	21.73		
Clips	12.00		
Graphite-epoxy prepreg tape	$460.00		
Fiberglass	2.25		
Bearings	24.50		
Adhesive	35.40		
Composite Parts			
Graphite-epoxy skin (2)		12.6	24.0
Fiberglass end rib (2)		5.2	9.9
Final Assembly		26.0	49.4
Subtotal	$904.88	43.8	
Quality Control		7.2	13.7
Production Control		1.6	3.0
Total		52.6	100.0

Table 10.—Average Composite Spoiler Fabrication Labor Hours

Operation	Labor man-hours	
	Hours	Percent
Graphite-epoxy skin layup and cure (upper and lower)	12.6	28.8
Fiberglass end rib fabrication	5.2	11.9
First-stage bond assembly, including core machining	10.5	24.0
Second-stage bond assembly	7.0	16.0
Painting, seal installation, bearing installation	8.5	19.4
Totals	43.8	100.1

(1) Average of 114 units produced

(2) Does not include tooling, production control, quality assurance R&D support of NDT

Table 11.—Graphite Composite Material Utilization

Composite used in fabrication of Task I spoilers	Amount	
	m	(ft)
Receiving inspection	244	(800)
In-process quality assurance	366	(1 200)
Skin layup	13 742	(45 056)
Trim, scrap, and other process losses	2 142	(7 024)
Unused material for laminate repairs	366	(1 200)
Composite used in fabrication of 900 environmental exposure specimens	366	(1 200)
Total purchased	17 226	(56 480)
Skins lost in process	1 074	(3 520)

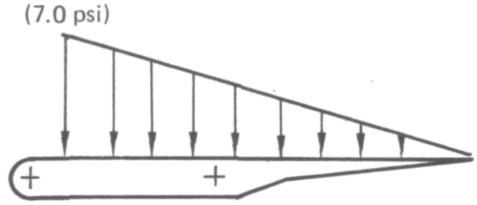
$$\text{Material utilization factor} = \frac{13\,742 - 1074}{13\,742 + 2142} = 79.6\%$$

CERTIFICATION TESTING

Before an aircraft structural component can be installed on a certificated commercial aircraft, it must be certificated under the applicable provisions of Federal Aviation Regulations Part 25. Section 25.305 of these regulations states, in part, "the structure must be able to support limit loads without detrimental permanent deformation" and "the structure must be able to support ultimate loads without failure for at least three seconds." These requirements formed the basis for certification of the graphite-epoxy spoiler.

Prior static testing had already established the strength level of the production 737 flight spoiler (65-46451) as 210% of design limit load. Static test of the flight spoiler was not required for certification of the 737 aircraft; it was conducted as a portion of an internal research and development effort at Boeing.

Figure 40 shows the static test setup used to apply the simulated airloads to the spoiler surface. Eight compression load pads are attached to the upper surface and interconnected by a system of beams to a single loading actuator to produce the same hinge moment as the design limit airload shown below. Figure 41 illustrates this critical loading method applied to the 737 aluminum spoiler.



All spoiler static testing was conducted to this design loading.

Since three spoiler assemblies incorporating three distinct graphite-epoxy material systems were fabricated, three separate certification tests were conducted, one on the first spoiler assembly produced of each type. Applied load and deflections of the spoiler were recorded in each test. Figure 42 shows the locations of the deflection gages. Testing results are summarized in table 12.

Plots of each test are shown in figures 43, 44, and 45, with the corresponding plot of the production aluminum spoiler shown in each figure for easy reference. Photos of the failed specimens are shown in figures 46 through 51.

Boeing Commercial Airplane Company
P.O. Box 3707
Seattle, Washington 98124
October 1, 1976

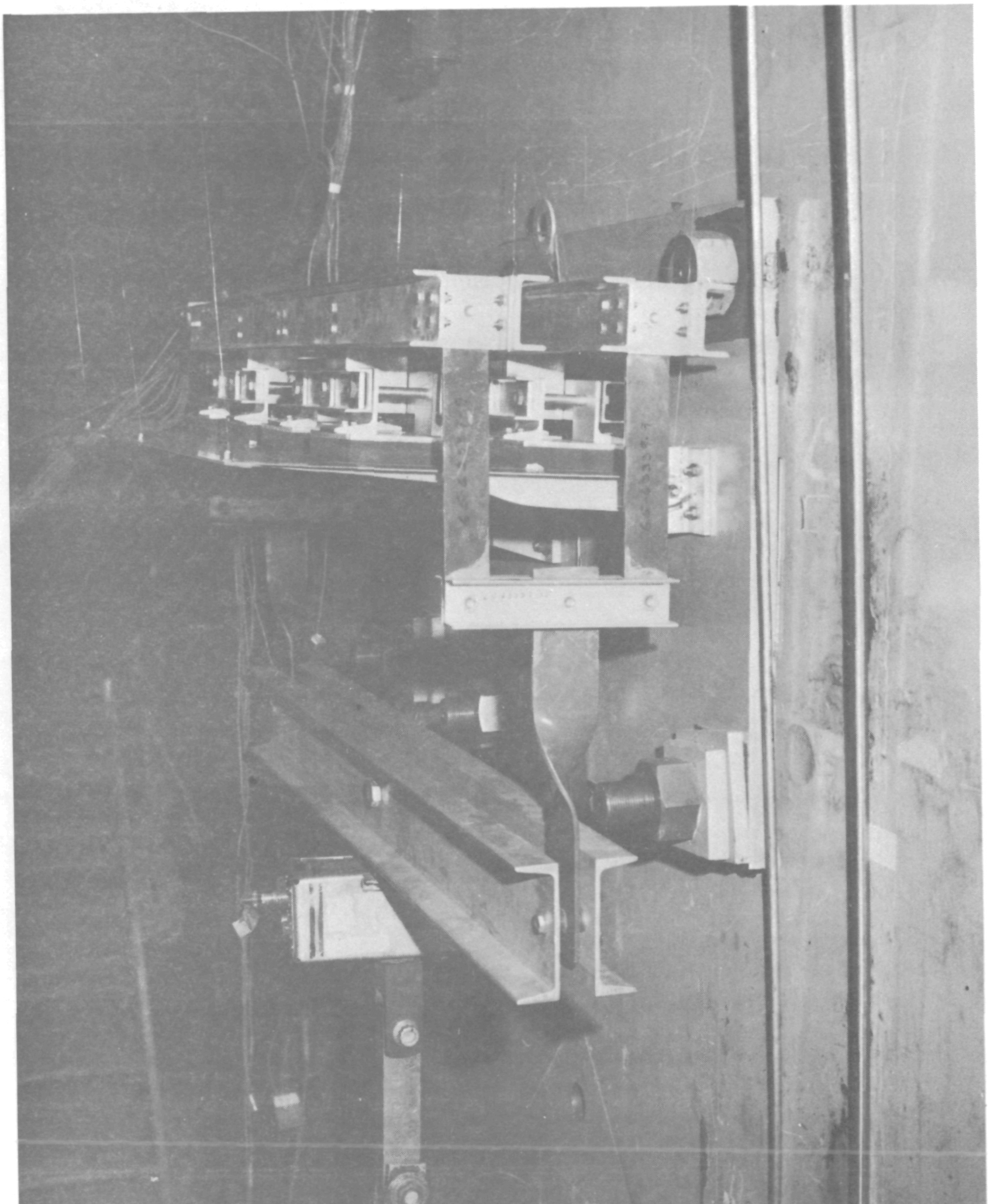


Figure 40.—Spoiler Static Test Setup

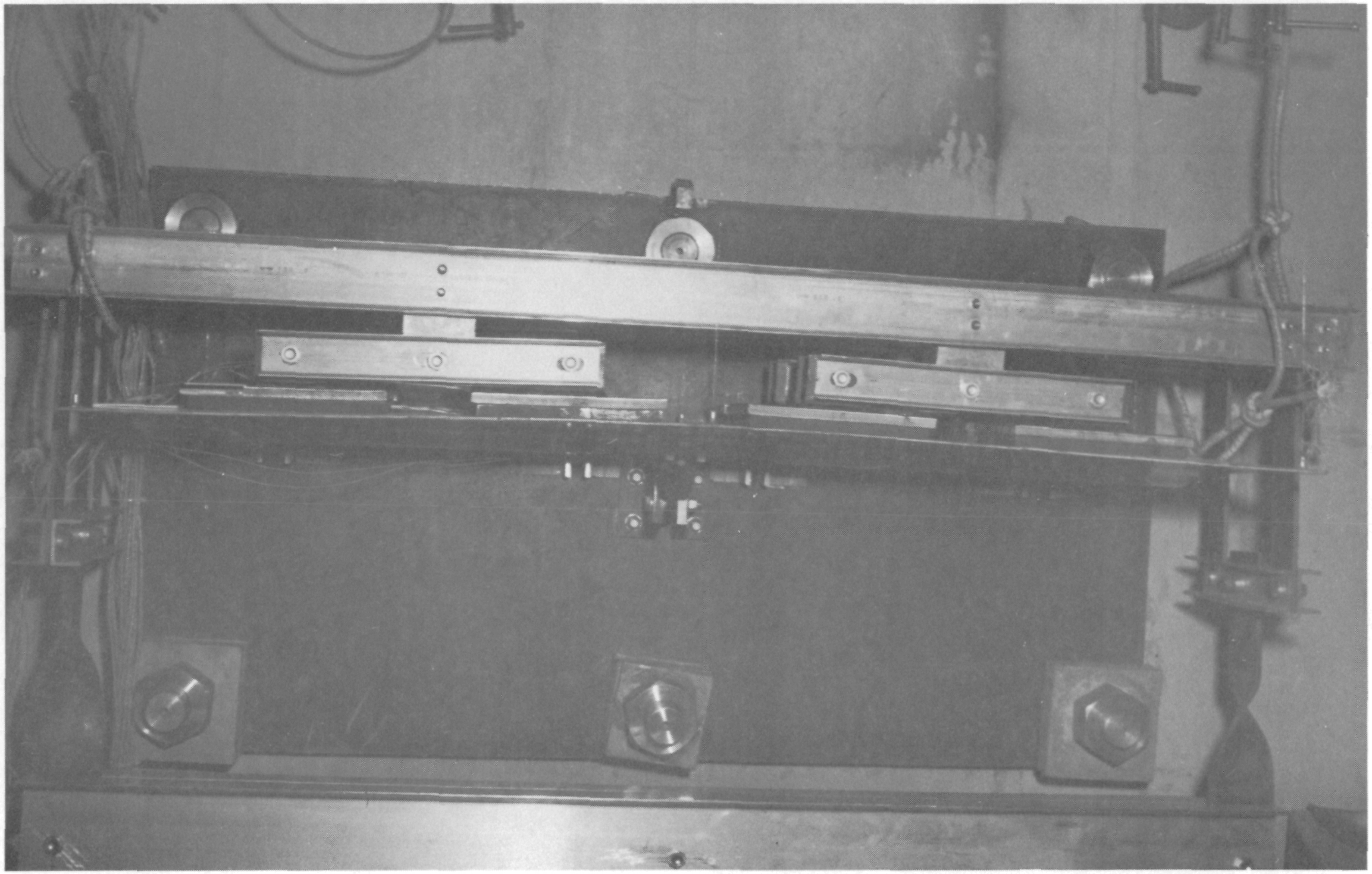


Figure 41.—737 Production Spoiler Under 100% Limit Load

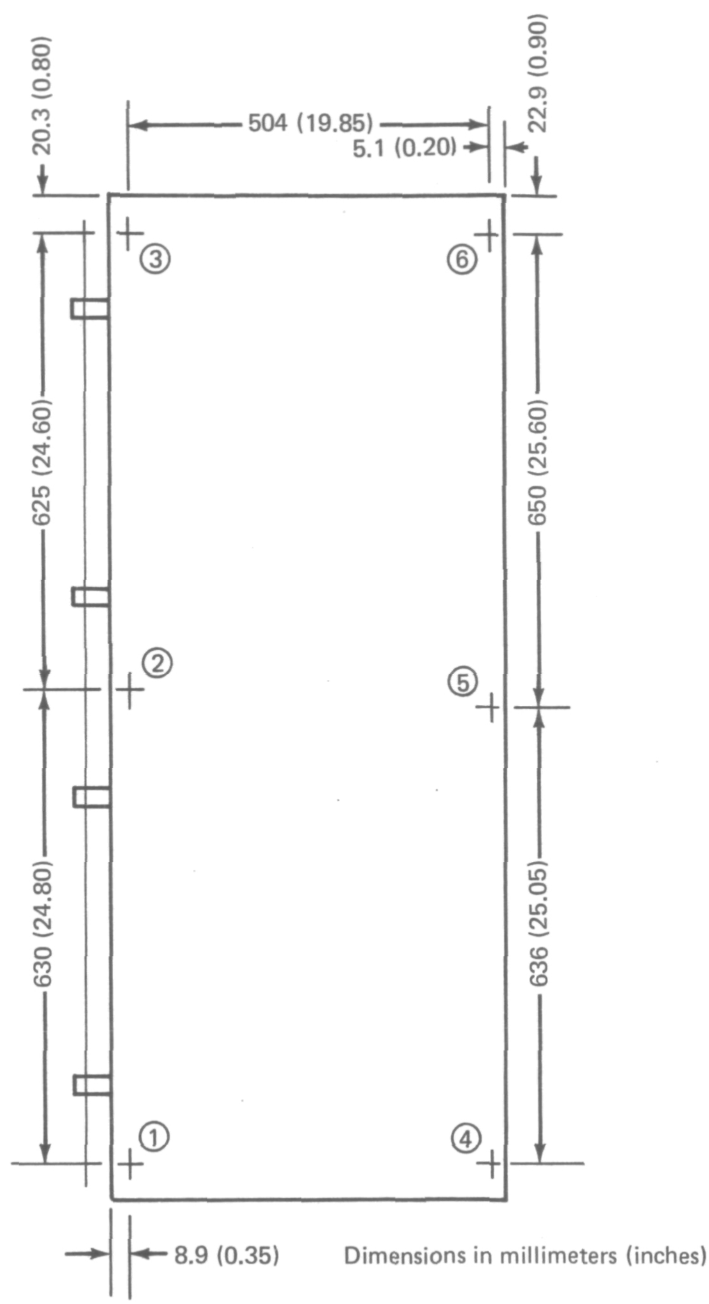


Figure 42.—Deflection Gage Locations—Static Test

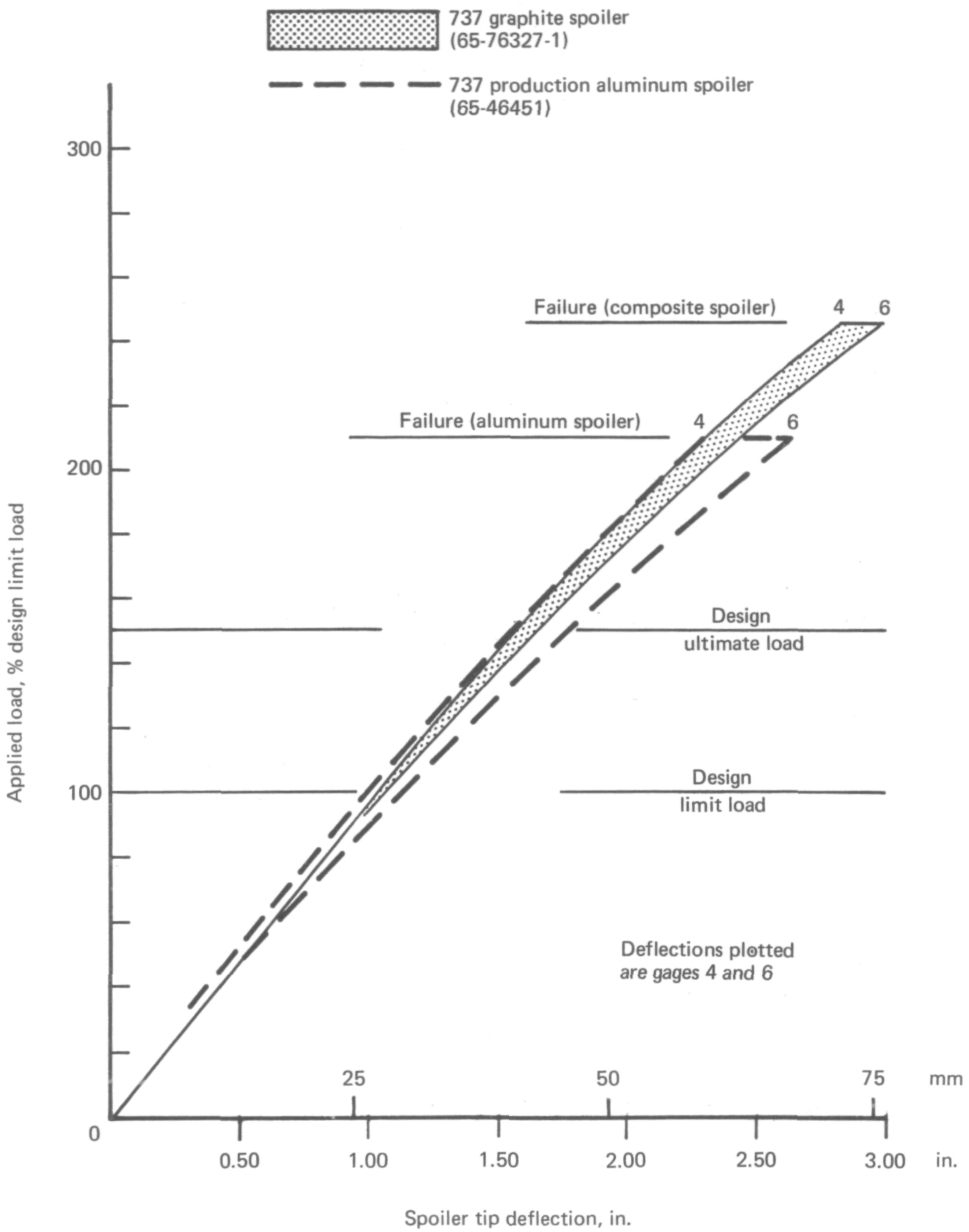


Figure 43.—Graphite Spoiler Tip Stiffness (Union Carbide 65-76327-1)

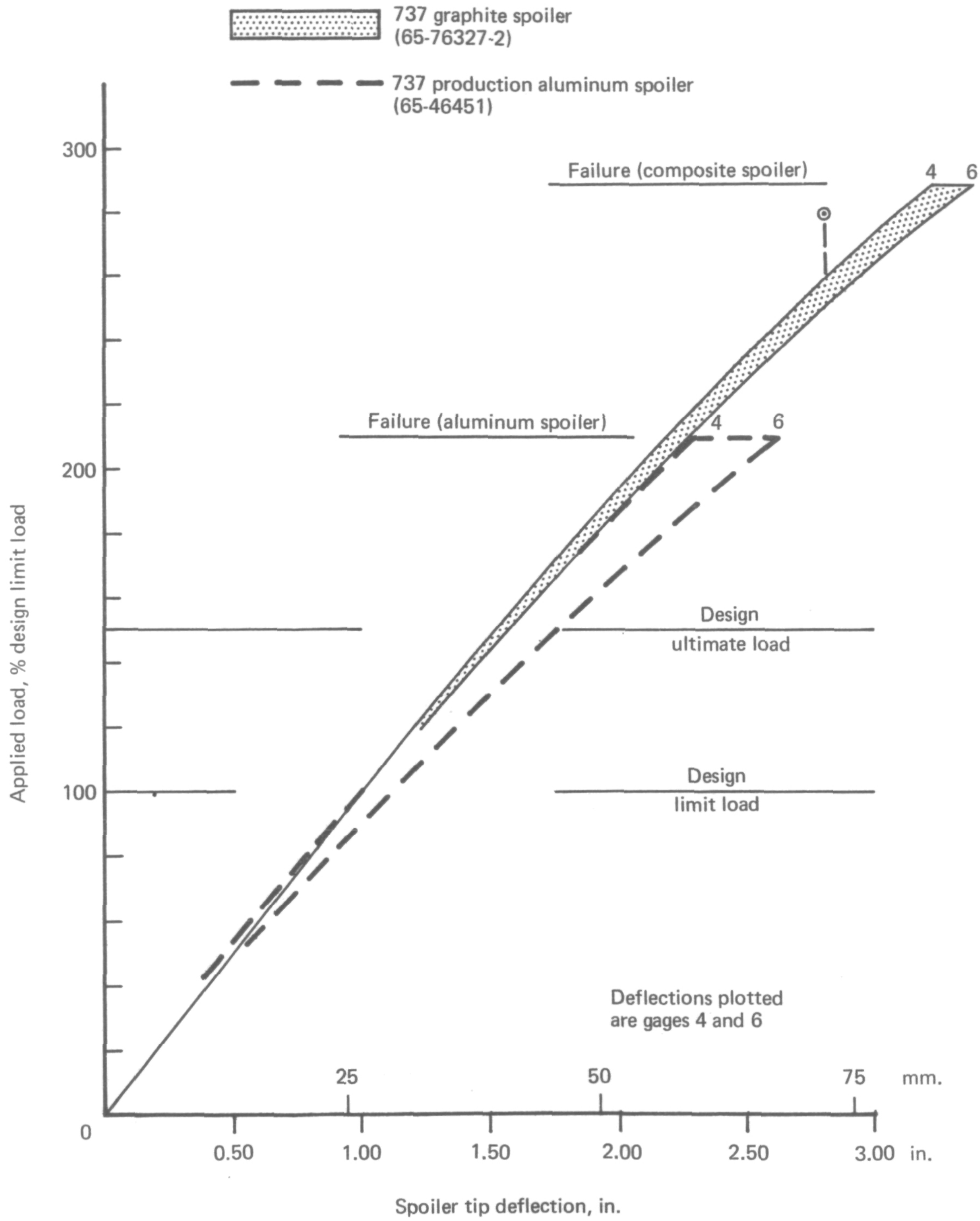


Figure 44.—Graphite Spoiler Tip Stiffness (Narmco 65-76327-2)

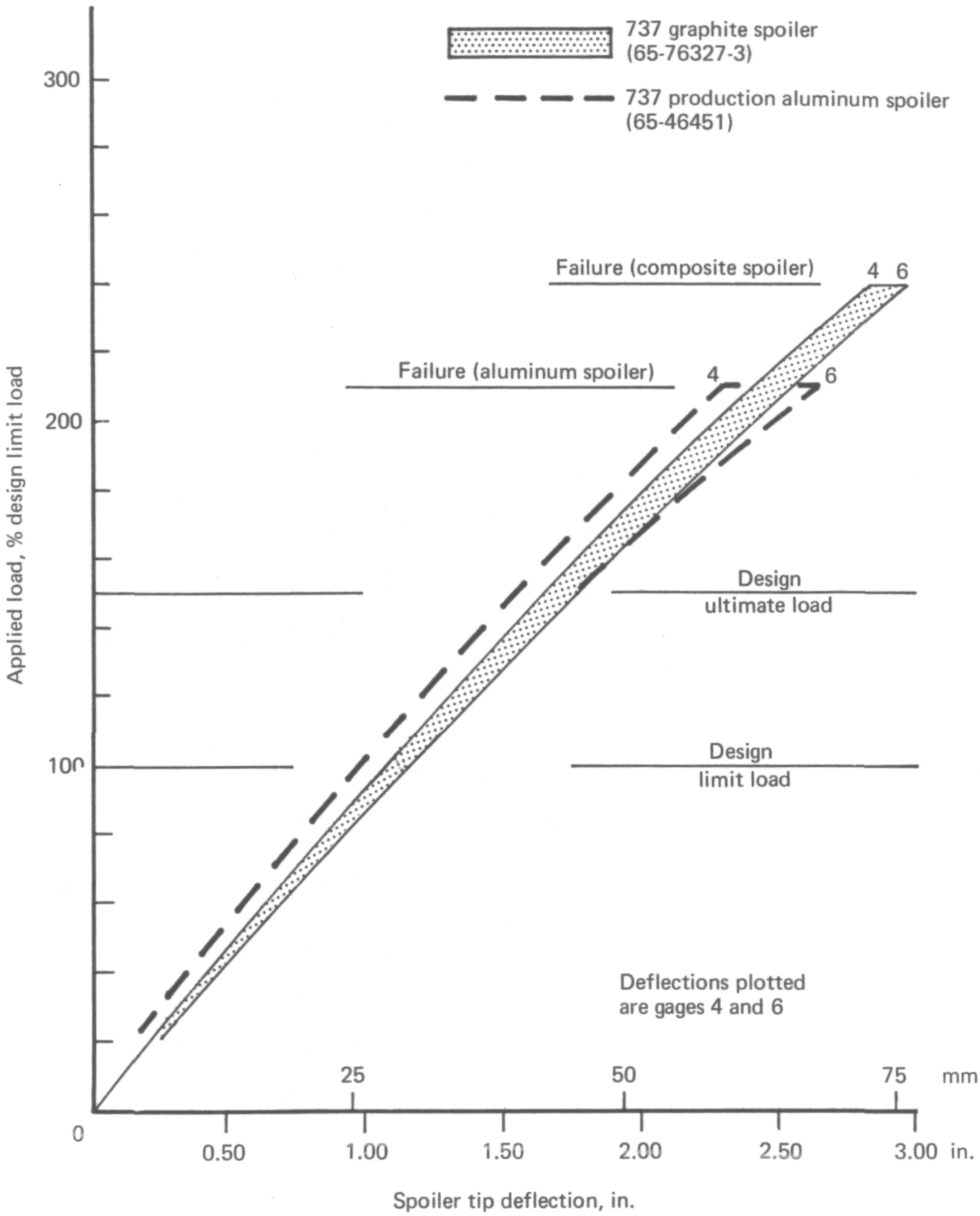


Figure 45.—Graphite Spoiler Tip Stiffness (Hercules 65-76327-3)

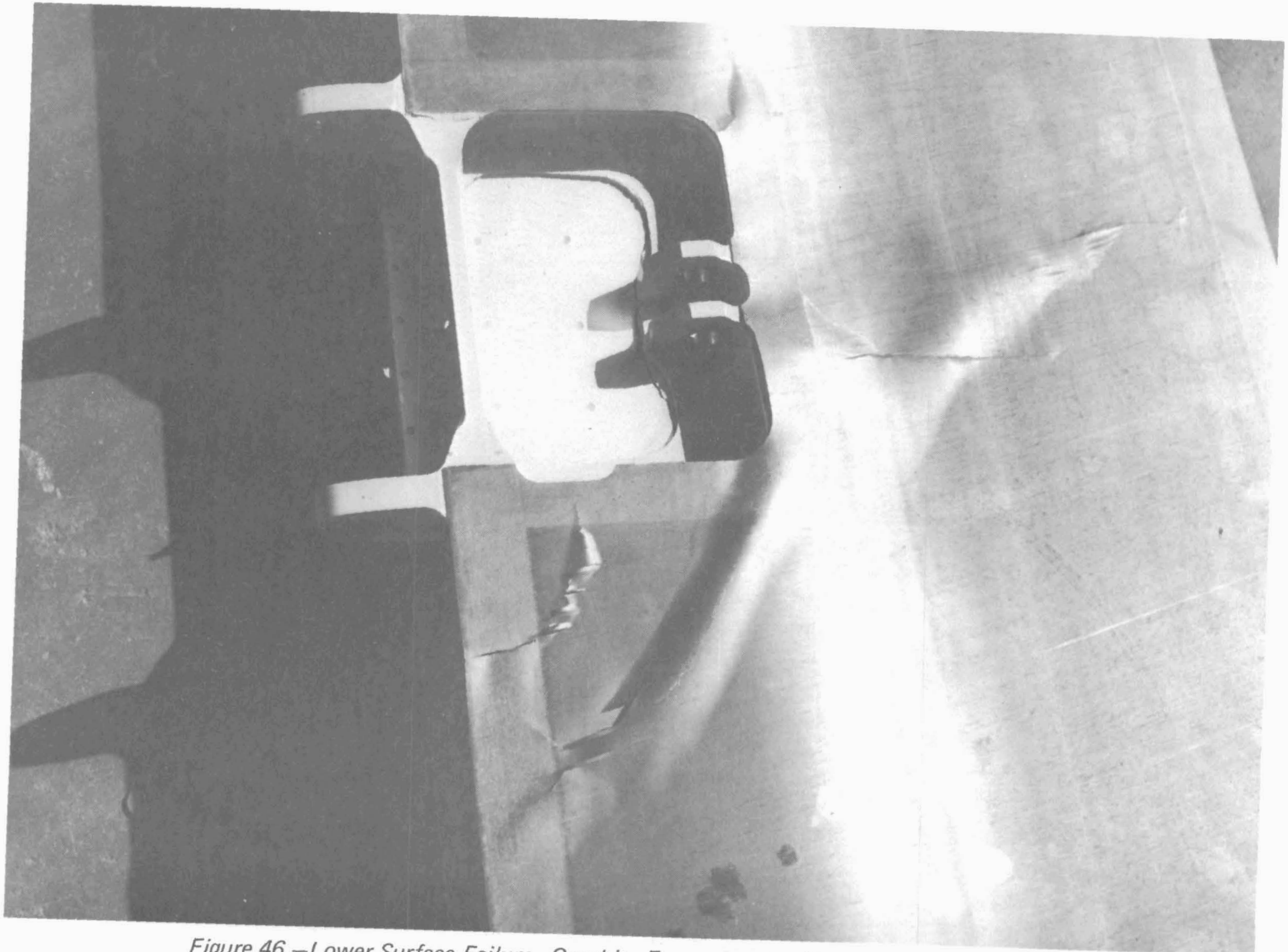


Figure 46.—Lower Surface Failure—Graphite-Epoxy Spoiler (Union Carbide 65-76327-1)

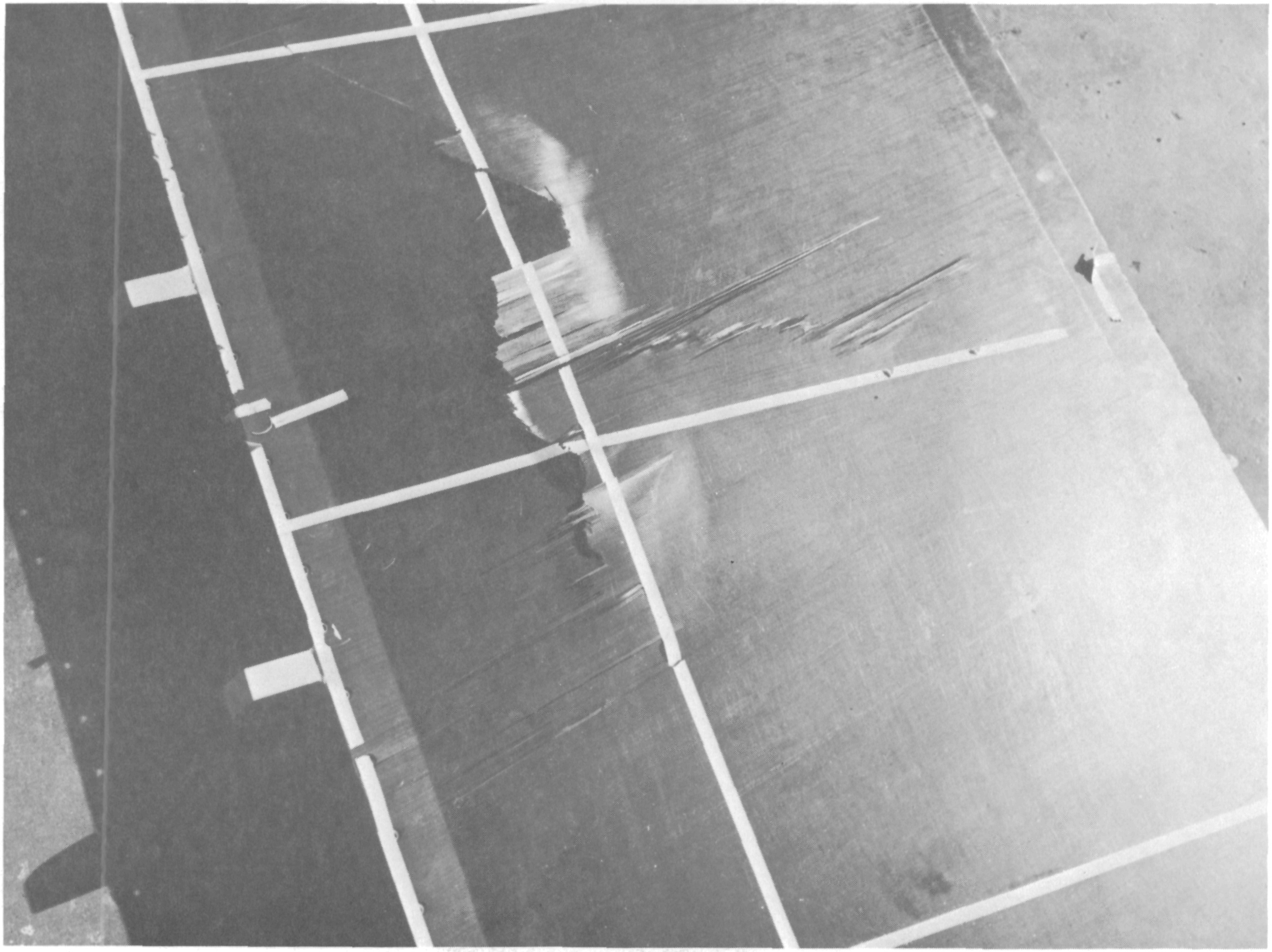


Figure 47.—Upper Surface Failure—Graphite-Epoxy Spoiler (Union Carbide 65-76327-1)

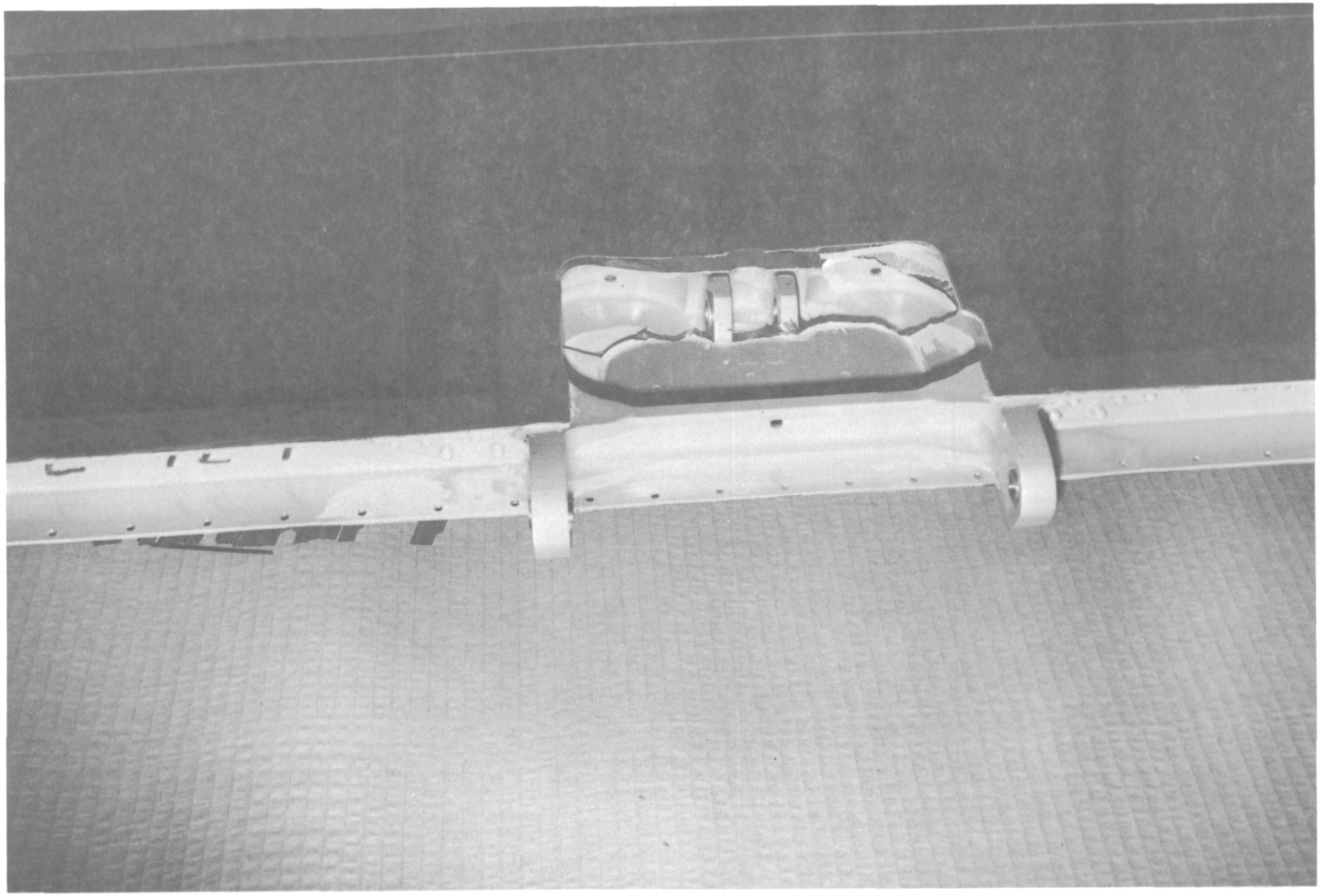


Figure 48.—Lower Surface Failure—Graphite-Epoxy Spoiler (Narmco 65-76327-2)

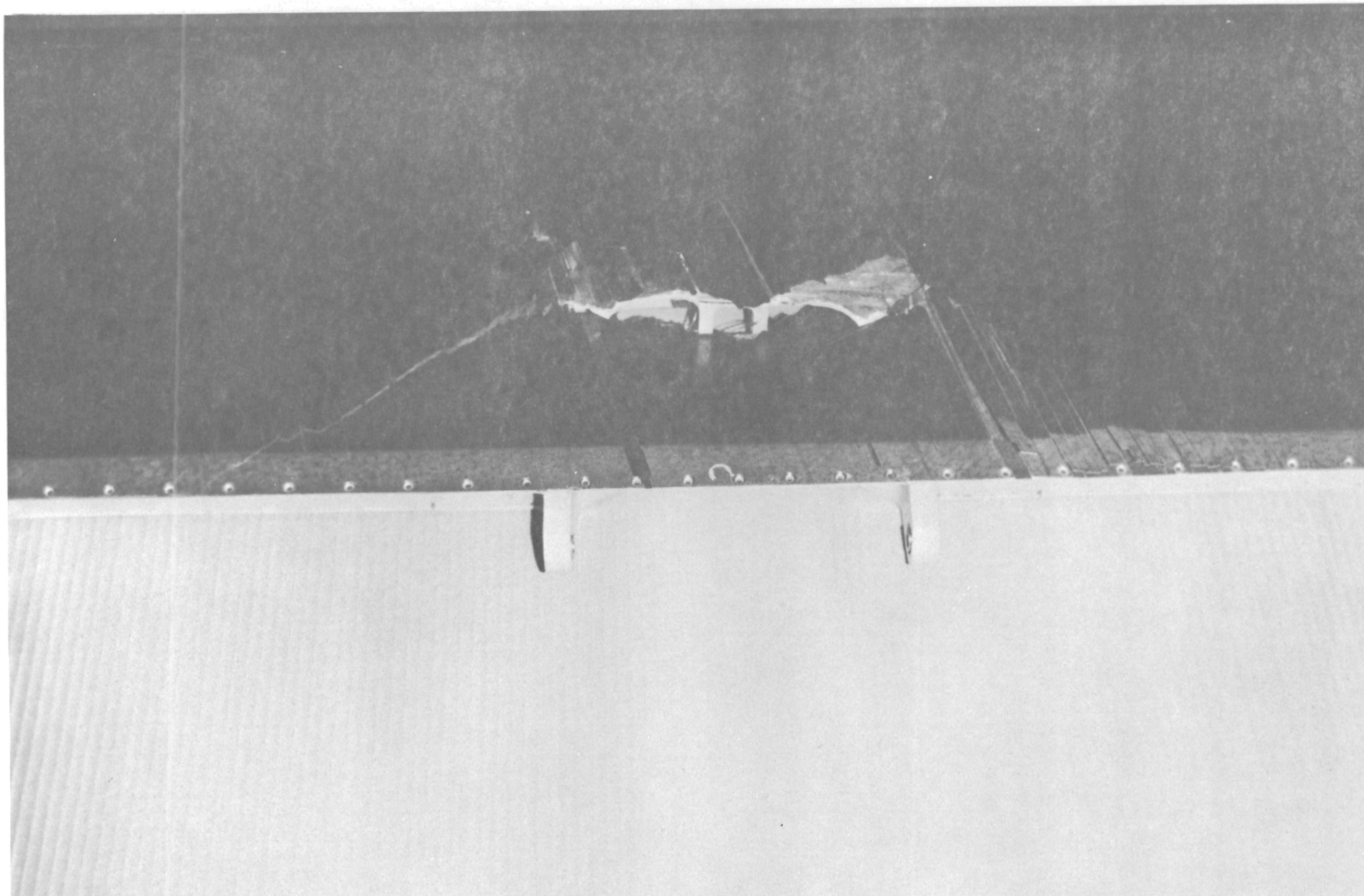


Figure 49.—Upper Surface Failure—Graphite-Epoxy Spoiler (Narmco 65-76327-2)

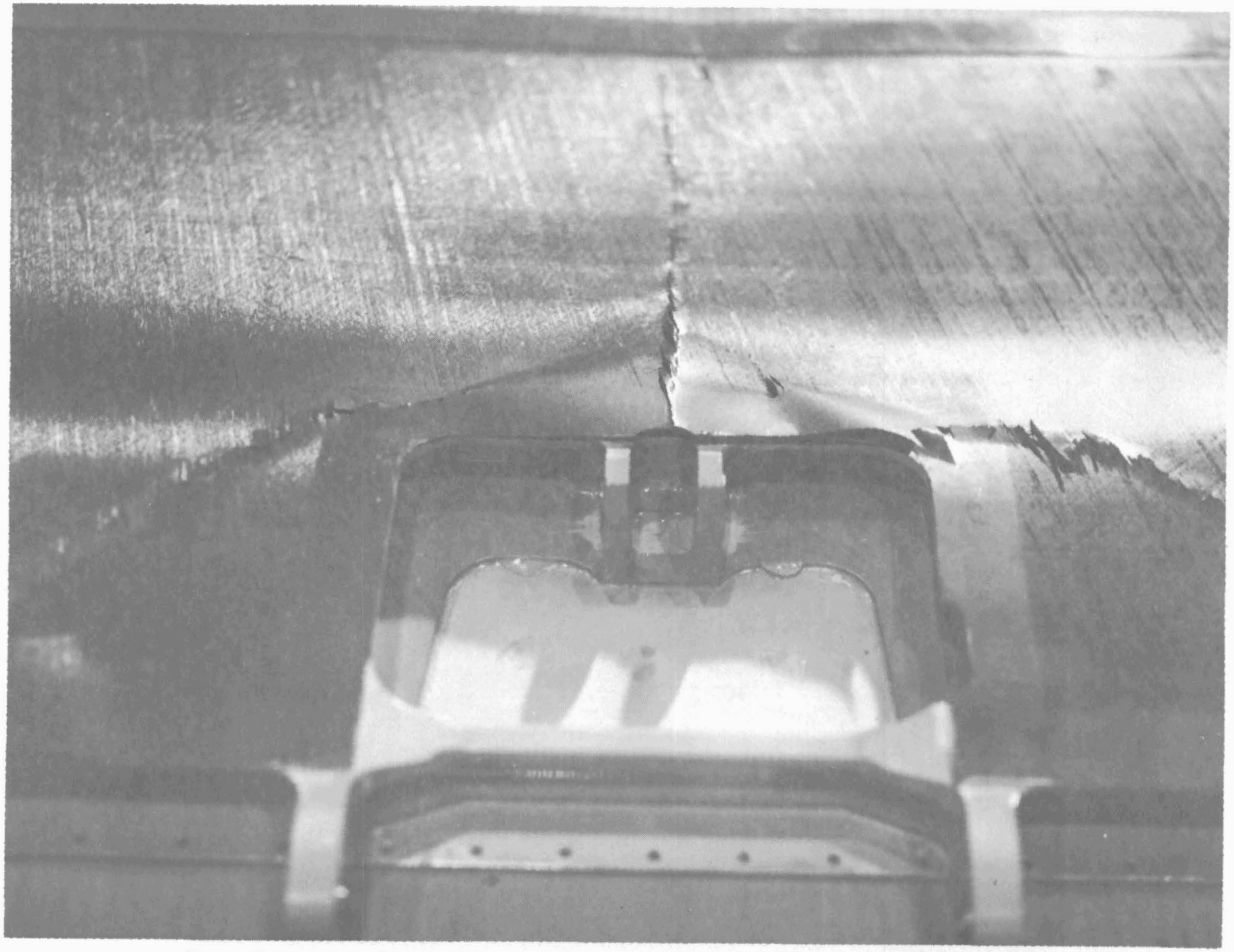


Figure 50.—Lower Surface Failure—Graphite-Epoxy Spoiler (Hercules 65-76327-3)

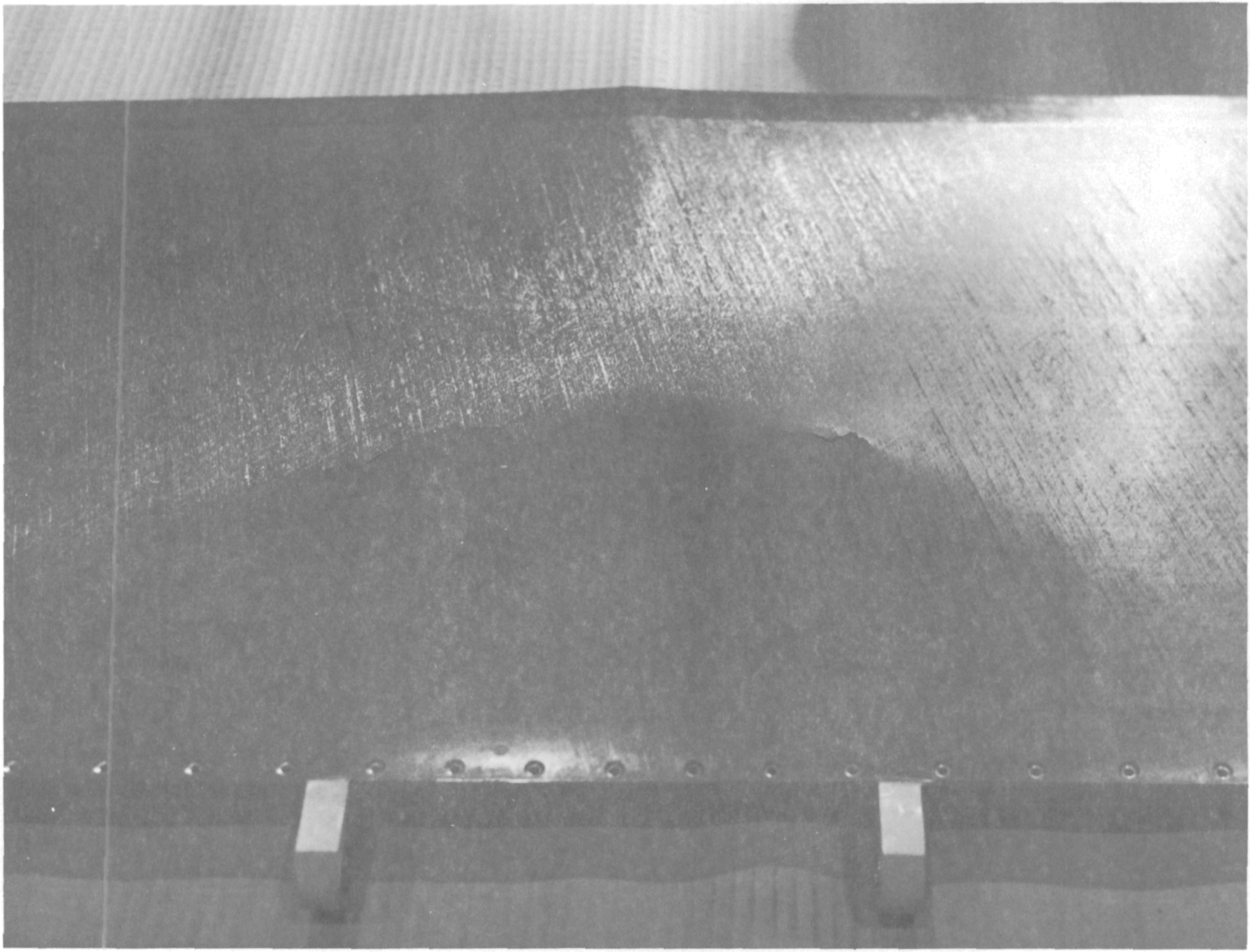


Figure 51.—Upper Surface Failure—Graphite-Epoxy Spoiler (Hercules 65-76327-3)

Table 12.—Test Spoiler Strength Comparisons

Test specimen	Ultimate strength, % design limit load	Ultimate strength requirement, per FAR 25, % design limit load	Failure description
65-76327-1 Serial number 0002 Union Carbide Thornel 300/2544	246	150	Failure of -11 aluminum upper surface doubler; yielding of 65-49507-8 fitting; secondary tensile failure of -8 graphite skin above -11 failure.
65-76327-2 Serial number 0041 Narmco Thornel 300/5209	289	150	Failure of 65-49507-8 fitting, followed by shear failure of -11 aluminum doubler; secondary tensile failure of -9 graphite skin above fitting failure.
65-76327-3 Serial number 0081 Hercules AS/3501	241	150	Compression failure of -7 graphite skin along aft edge of 65-49507-8 fitting; secondary failure of honeycomb core and lower skin along spoiler centerline.
65-46451 737 production aluminum	210	150	Failure of upper surface skin in tension above 65-49507-8 fitting.

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APPENDIX

ENGINEERING DRAWING 65-76327

Sheets 1, 2, and 3

DIMENSIONING & TOLERANCING PER USAS Y14.5
PART MARKING PER BAC 5307
SEE BACD 2097 FOR SURFACE ROUGHNESS
FORM, PUNCH, STRAIGHTEN & FIT METAL PARTS PER BAC 5300
BOLT & NUT INSTALLATION PER BAC 5009
MATERIAL SUBSTITUTION & EQUIVALENTS PER BAC 5005
SST MATERIALS SUBSTITUTIONS & MANUFACTURING PROCESSES PER D6-19736
FOR FINISH CODES, SEE DOCUMENT D2-5000 &/OR D6-5000

FASTENER SYMBOL CODE

INSTL: STD, PER BAC 5004; FLUID TIGHT, PER BAC 5047
BASIC CODE — ENCLOSED = FLUID TIGHT, OPEN = STANDARD
DIA DASH NO.
MFD HEAD LOC — N = NEAR SIDE, F = FAR SIDE
XX | XX
D2C | XW
DIMPLE/CSK INFO — D = DIMPLE, 2 = NO. SH DIMPLED, C = CSK INSTRUCTURE, 2 LINES: TOP = MFD HD; BOTTOM = DRIVEN HD
SPOT WELD OPT
LENGTH DASH NO.
NOTE: PROTRUDING HD RIVETS DRIVEN FLUSH. D/C INFO (2 LINES) APPLIES TO DRIVEN HD ONLY

HOLE LOCATION FOR 1/16 DIAMETER RIVET
HOLE LOCATION FOR 1/16 DIAMETER BOLT

= NAS1399MW	= MS20470D
= MS20470B	= BACB30LP

-4	-3	-2	-1	QTY REQD	PART OR IDENTIFYING NUMBER	NOMENCLATURE OR DESCRIPTION	ZONE	MATERIAL AND SPECIFICATION	HT-TR	FINISH	PT-MK	REV LTR
	✓	✓	✓	2	NAS1399MW5-2	GROUNDING RIVET						
	✓	✓	✓	1	MS27253-1	PLATE, IDENTIFICATION					[15]	
	✓	✓	✓	2	BACJ40K-5A5A6	GROUNDING WIRE						
	✓	✓	✓	2	10-60545-144	BEARING - TEFLON SELF-ALIGNING						
	✓	✓	✓	2	MS16625-1100	RETAINING RING						
✓				10	BACB30GP6-3	BOLT						
	✓	✓	✓	4	BAC1524-30	SHIM						
	✓	✓	✓	4	NAS1103-4W	BOLT						
	✓	✓	✓	55	BACN10JC08	NUT						
	✓	✓	✓	8	BACN10JC3	NUT						
✓				16	BACB30GP5-2	BOLT		[18]				
	✓	✓	✓	2	NAS514P832-7	▲						
	✓	✓	✓	53	BACB30LU2-2							
	✓	✓	✓	4	BACB30NE3-4	▼						
	✓	✓	✓	4	BACB30LU3-4	BOLT						
	✓	✓	✓	55	AN960PD8L	WASHER						
	✓	✓	✓	8	AN960PD10	WASHER						
	✓	✓	✓	8	NAS679A3W	NUT						
✓				16	NAS1080D5	COLLAR						
✓				1	65-76301-2	END RIB						
✓				1	65-76301-1	END RIB						
✓				2	69-37570-1	SLOTTED HINGE FITTING				F-2.30		
✓				1	65-49507-8	HINGE FITTING ASSY				F-20.26		
✓				1	65-46451-18	L.E. CHANNEL						
✓				1	65-46451-17	L.E. CHANNEL						
✓				2	65-46451-22	CLIP						
✓				4	65-46451-21	CLIP				F-20.26		
✓				10	NAS1080D6	COLLAR						
	✓	✓	✓	2	-23	DOUBLER		.016 THK [7]			R	
	✓	✓	✓	1	-22	FILLER		[7] [11] .020 THK × .60 × 8.60		F-20.26	R	
✓				1	-21	HONEYCOMB CORE		BMS 4-4 TYPE 3-10				
					20							
	✓	✓	✓	2	-19	FILLER (END SEAL)		[7] [11] .020 THK × .60 × 13.20		F-20.26		
	✓	✓	✓	1	-18	SEAL		[6] × 8.60 LONG			R	
	✓	✓	✓	2	-17	SEAL		[6] × 14.47 LONG			R	
	✓	✓	✓	1	-16	OPP -15						
	✓	✓	✓	1	-15	SEAL		[6] × 5.90 LONG			R	
	✓	✓	✓	1	-14	OPP -13						
	✓	✓	✓	1	-13	SEAL END		[6] × 15.40 LONG			R	
	✓	✓	✓	1	-12	PHENOLIC STRIP		[5] [10] .040 THK × 1.20 × 52.00			T	
	✓	✓	✓	1	-11	METAL SHIM		[7] .016 THK × 3.23 × 52.00		F-20.26	R	
	✓			1	-10	UPPER SURFACE SKIN LAMINATE		[4] [14]				
		✓		1	-9	UPPER SURFACE SKIN LAMINATE		[3] [14]				
			✓	1	-8	UPPER SURFACE SKIN LAMINATE		[2] [14]				
	✓			1	-7	LOWER SURFACE SKIN LAMINATE		[4] [14]				
		✓		1	-6	LOWER SURFACE SKIN LAMINATE		[3] [14]				
			✓	1	-5	LOWER SURFACE SKIN LAMINATE		[2] [14]				
—	✓	✓	✓	1	-4	HONEYCOMB ASSY		[14] [12] [8]				
	—			—	-3	PANEL ASSY FLIGHT SPOILER		[12] [13]		[17]		
		—		—	-2	PANEL ASSY FLIGHT SPOILER		[12] [13]		[17]		
			—	—	-1	PANEL ASSY FLIGHT SPOILER		[12] [13]		[17]		

RELEASE — LIST OF MATERIAL

[19] XFW6 FASTENERS IN .187 $^{.190}_{.187}$ DIA. HOLES

[18] XFW5 FASTENERS IN .160 $^{.164}_{.160}$ DIA HOLES

[17] FOR COMPOSITE SURFACES: SRF-14.672 + SRF-14.68 + SRF-14.9813
FOR METALLIC SURFACES: SRF-20.02 + SRF-14.9813

[16] GROUNDING FASTENER - USE NAS1399MW5-2

[15] APPLY MARKING PER 66-11324 PRIOR TO AFFIXING TO PANEL ASSY

[14] FABRICATE PER D6-32541

[13] SEAL ALL OPENINGS AND FASTENERS WHICH PENENTRATE TO THE CORE AREA PER BAC 5503 (SKYDROL RESISTANT METHOD REQUIRED)

[12] BOND PER BAC 5514-551 (SERIAL NO 1 ONLY); BOND PER BAC 5514 EXCEPT PHOSPHORIC ACID ANODIZE PLUS BMS 5-89 AND EA 9628 ADHESIVE (SERIAL NO 2 AND ON)

[11] BOND PER BAC 5010 WITH TYPE 38

[10] BOND TO PANEL ASSY (-1, -2 OR -3) PER 5010 WITH TYPE 44

[9] SHIM GAPS GREATER THAN .005 - MAX GAP PERMITTED BEFORE CLAMP UP = .005

[8] FOAM PER BAC 5514-590 WITH BMS 5-90, TYPE 2, CLASS 250, GRADE 100 ALL CONTACT AREA BETWEEN THE CORE (-21) AND L.E. CHANNELS, END RIBS & THE CENTER HINGE FITTING

[7] 7075-T6 CLAD SHEET PER QQ-A-287

[6] SEAL SECTION PER 10-60754-238

[5] LAMINATED THERMOSETTING SHEET COTTON FABRIC, PHENOLIC RESIN MIL-P-15035 TYPE FBM

[4] GRAPHITE-EPOXY PREPREG FROM SUPPLIER No 3 PER D6-32541

[3] GRAPHITE-EPOXY PREPREG FROM SUPPLIER No 2 PER D6-32541

[2] GRAPHITE-EPOXY PREPREG FROM SUPPLIER No 1 PER D6-32541

[1] BMS 5-51 TYPE 2 ADHESIVE FILLER STRIP (UP TO .015 THICK) OPTIONAL IN THIS AREA

NEXT ASSY	USED ON	SECT NO	SERIAL NUMBER	PART NUMBER	RELEASE COLUMN INDICATOR	DRAWING SHEET NUMBER
APPLICATION						

CHANGE NO
DWG ORIG BY (GROUP) ASDS

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES
TOLERANCES: ANGLES ±1° DECIMALS ±.03
RIVET & BOLT EDGE MARGINS ± .05
SHEET METAL CORNER RADII
INTERNAL .16 $^{.19}_{.16}$
EXTERNAL .23 $^{.25}_{.00}$
BEND RADII: ± .01 ON .03 & .06; ± .02 ON .09 & GREATER

DRAWN J DUKES — DATE 6-3-72
CHECKED
STRESS
ENGR — 7-72
GROUP
PROJ

THE BOEING COMPANY
COMMERCIAL AIRPLANE DIVISION RENTON

PANEL ASSY
737 FLIGHT SPOILER
NAS1 11668 TASK I

CODE IDENT NO 81205 — SIZE J — 65-76327

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FORM, PUNCH, STRAIGHTEN & FIT METAL PARTS PER BAC5300
BOLT & NUT INSTALLATION PER BAC 5009
MATERIAL SUBSTITUTION & EQUIVALENTS PER BAC 5005
SST MATERIALS SUBSTITUTIONS & MANUFACTURING PROCESSES PER D6-19736
PART MARKING PER BAC 5307
SEE BACD 2097 FOR SURFACE ROUGHNESS
FOR FINISH CODES, SEE DOCUMENT D2-5000 &/OR D6-5000

DIMENSIONING & TOLERANCING PER USAS Y14.5
UNLESS OTHERWISE SPECIFIED
DIMENSIONS ARE IN INCHES
TOLERANCES:
ANGLES ± DECIMALS ±
RIVET & BOLT EDGE MARGINS ± .05
SHEET METAL CORNER RADII
BEND RADII:
± .01 ON .03 & .06
± .03 ON .09 & GREATER

USED ON: TEST ONLY	DRAWN: J DUKES	DATE: 72	THE BOEING COMPANY, COMMERCIAL AIRPLANE DIVISION, RENTON, WASH.
SECT NO.	CHECKED		PANEL ASSY 737 FLIGHT SPOILER NAS1 11668 TASK I
CHG NO.	STRESS / ENGR / GROUP / PROJ		CODE IDENT NO. 81205 — SIZE J — 65-76327
GROUP ORG: ASDS			SCALE: NOTED — SH. 2

SEE SHEET 1 OR PL FOR LIST OF MATERIAL, USAGE AND NOTES

65-76327 SHEET 2

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-5,-6 & -7 LOWER SURFACE SKIN LAMINATE
-8,-9 & -10 UPPER SURFACE SKIN LAMINATE
86.00 TYP
65-76327 3
FULL SIZE METAL OR MYLAR COPIES OF THIS DRAWING ARE AVAILABLE FOR SHOP USE
B BEND
DN DOWN
OML OUTSIDE MOLD LINE
IML INSIDE MOLD LINE
℄B CENTERLINE OF BEND
.250 .260/.247 DIA TOOL HOLE (USE OPTIONAL)
FORM, PUNCH, STRAIGHTEN & FIT METAL PARTS PER BAC5300
BOLT & NUT INSTALLATION PER BAC 5009
MATERIAL SUBSTITUTION & EQUIVALENTS PER BAC 5005
SST MATERIALS SUBSTITUTIONS & MANUFACTURING PROCESSES PER D6-19736
PART MARKING PER BAC 5307
SEE BACD 2097 FOR SURFACE ROUGHNESS
FOR FINISH CODES, SEE DOCUMENT D2-5000 &/OR D6-5000
DIMENSIONING & TOLERANCING PER USAS Y14.5
UNLESS OTHERWISE SPECIFIED
DIMENSIONS ARE IN INCHES
TOLERANCES:
ANGLES ± 1° DECIMALS ±.03
RIVET & BOLT EDGE MARGINS ±.05
SHEET METAL CORNER RADII
BEND RADII: ±.01 ON .03 & .06 ±.03 ON .09 & GREATER
USED ON TEST ONLY
SECT NO.
CHG NO.
GROUP ORG ASDS
DRAWN J DUKES
CHECKED
STRESS
ENGR
GROUP
PROJ
DATE
SEE SHEET 1 OR PL FOR LIST OF MATERIAL, USAGE AND NOTES
THE BOEING COMPANY
COMMERCIAL AIRPLANE DIVISION RENTON, WASH
PANEL ASSY
737 FLIGHT SPOILER
NAS1-11668 TASK 1
CODE IDENT NO 81205
SIZE J
65-76327
93

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3. Billington, J. P.: *Fabrication and Inspection Requirements for NASA Contract NAS 1-11668, 737 Graphite-Epoxy Flight Spoilers.* D6-32541, Boeing Commercial Airplane Company, June 11, 1973.

4. Thompson, V. S.: *Improved Tooling for Large Structural Components, Final Report, July 19, 1971–July 18, 1972.* AFML-TR-72-198, Boeing Commercial Airplane Company, October 1972.